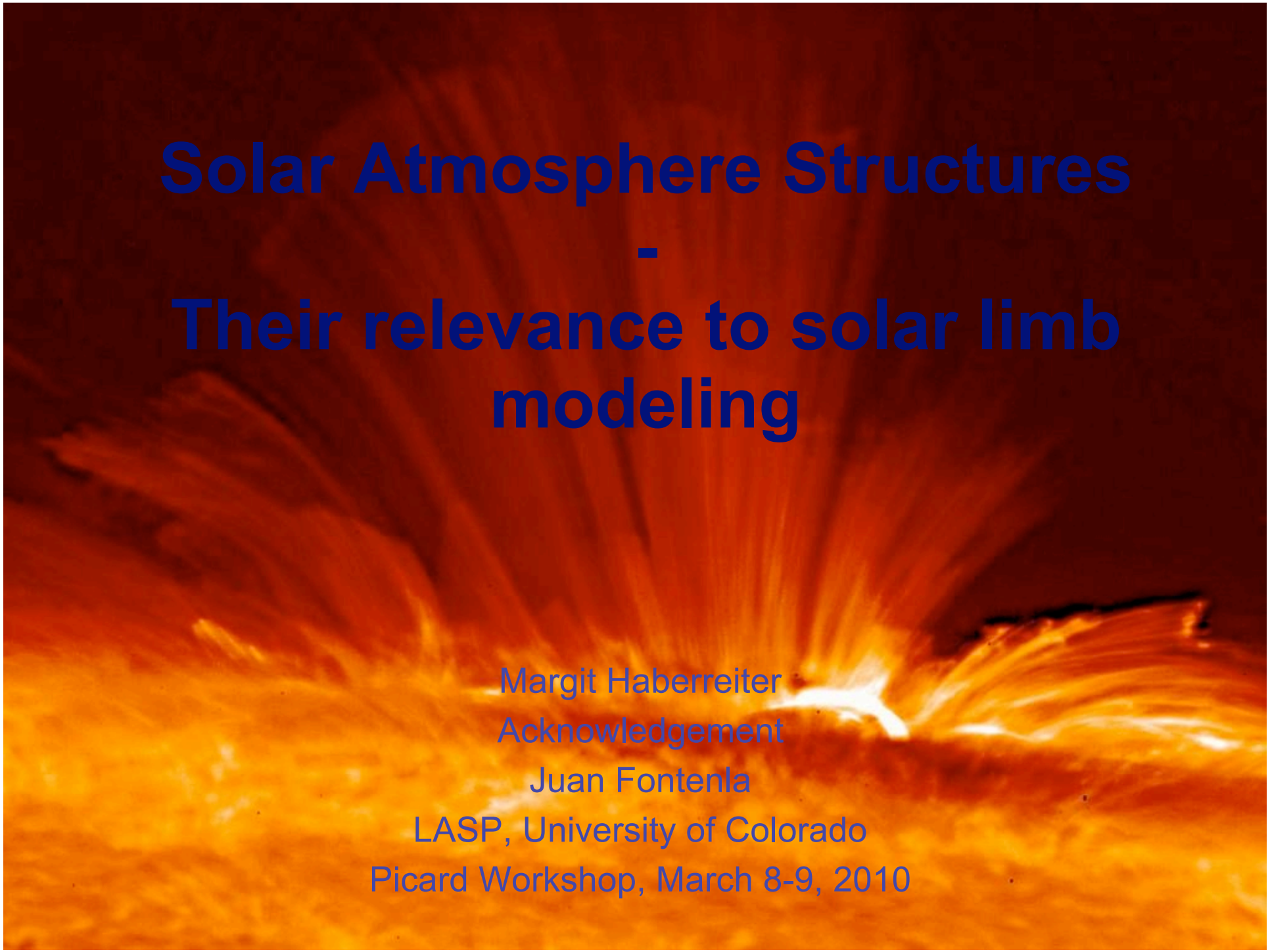

Solar Atmosphere Structures - Their relevance to solar limb modeling

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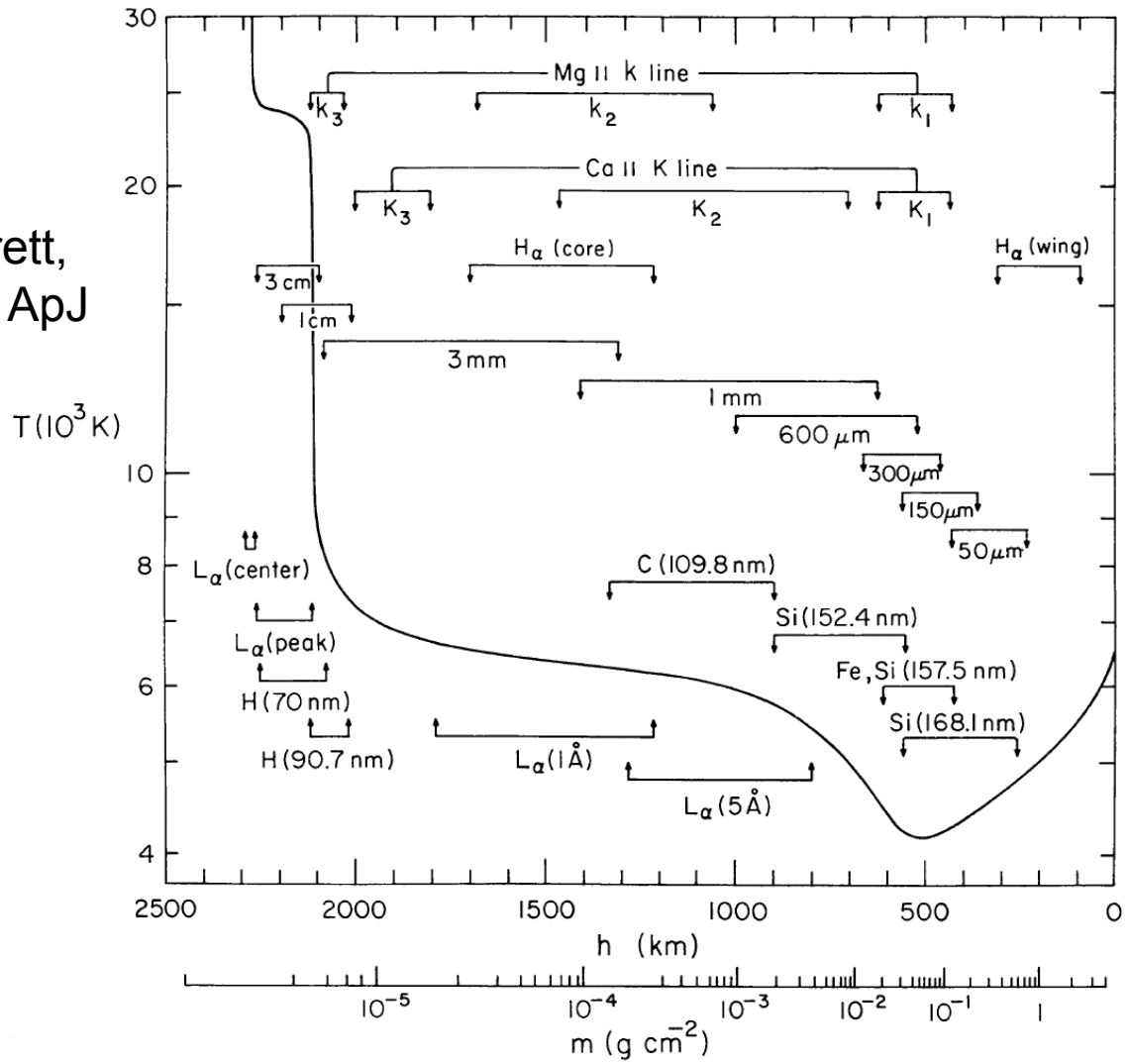
Overview

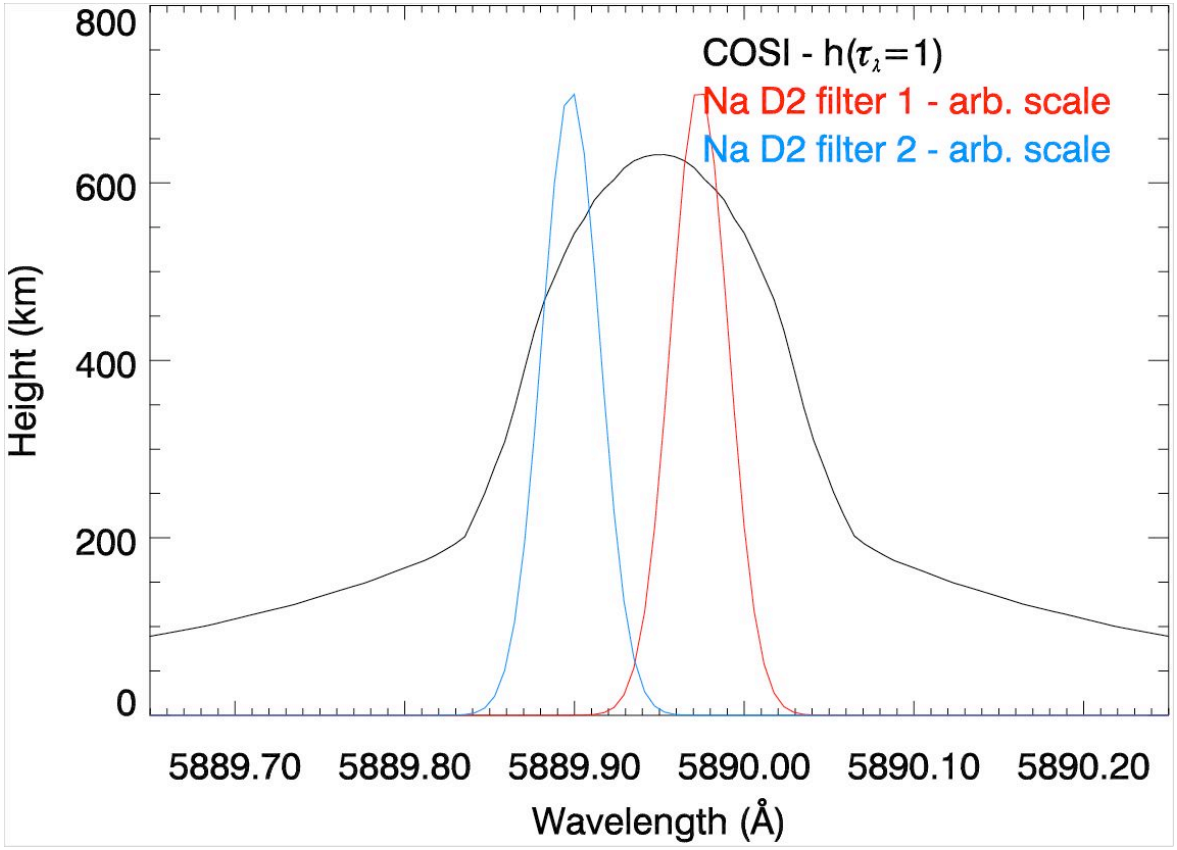
- Formation height
- Details about latest atmosphere structures by Fontenla et al., 2009
- Spectral synthesis in spherical symmetry
- Results

Formation Heights

Vernazza, Avrett, Loeser, 1981, ApJ



Formation height of spectral line



Example of Formation Height For Na D2

Attention: Static atmosphere

Kappa total = kappa continuum + kappa line, optically thick lines -> change Of the height (i.e. Temperature) where the radiation comes from

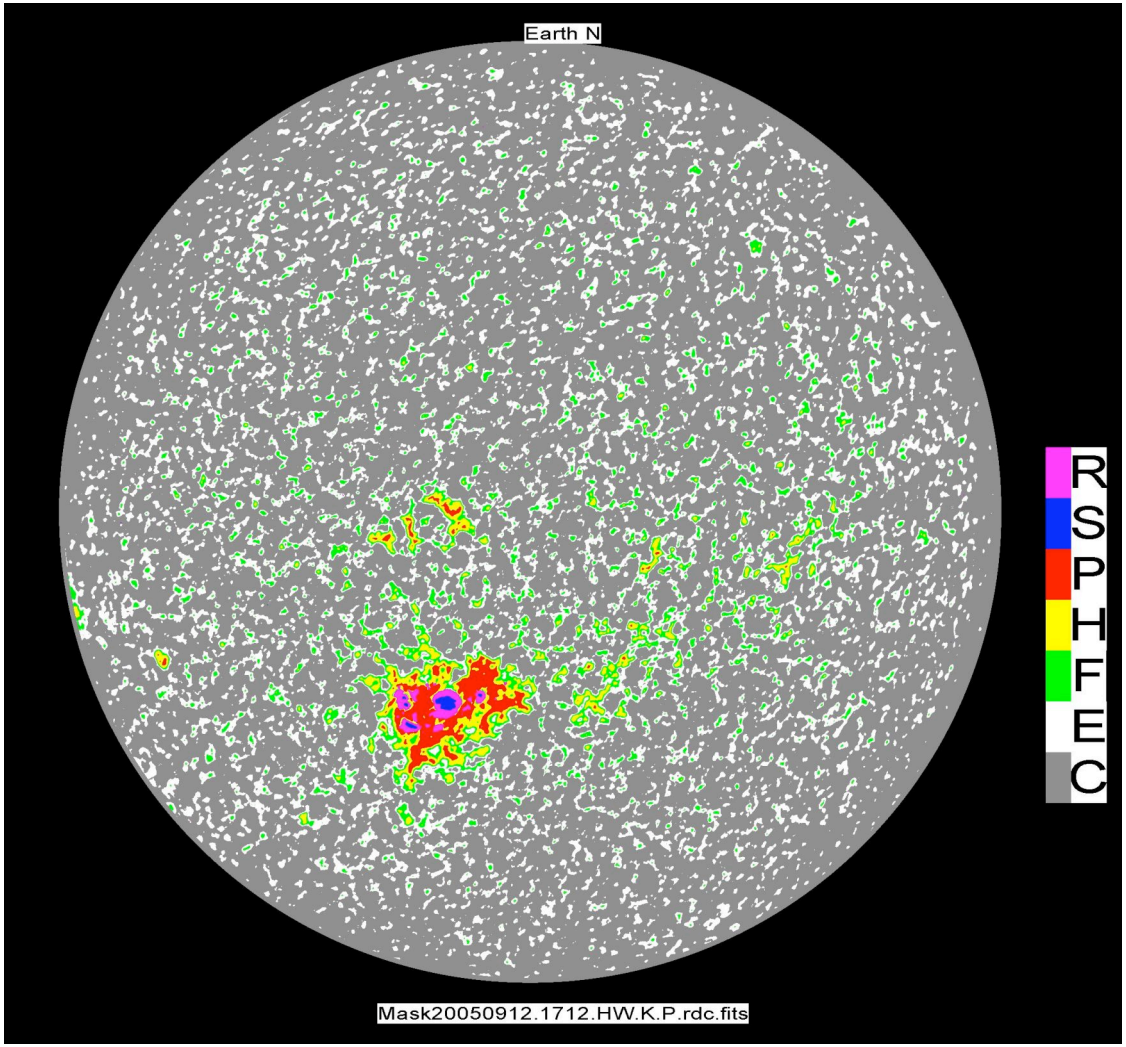
Solar **R**adiation **P**hysical **M**odeling (SRPM)

- **Multi level atoms**
  - 373 ions, from H to Ni with ioncharge 25
  - ~14’000 atomic levels
  - ~170’000 spectral lines
  - Statistical equation is solved to get the level populations

- **Chromosphere and transition region**
  - for ioncharge ≤ 2:
  - full NLTE (Fontenla et al., 1999; 2006; 2007)
  - plus optically thin transition region lines

- **Corona**
  - ioncharge >2
  - optically thin, i.e. collisions and spontaneous emission
  - Line of sight integration accounts for opacity
  - Spherical symmetry

Masks from Precision Solar Photometric Telescope



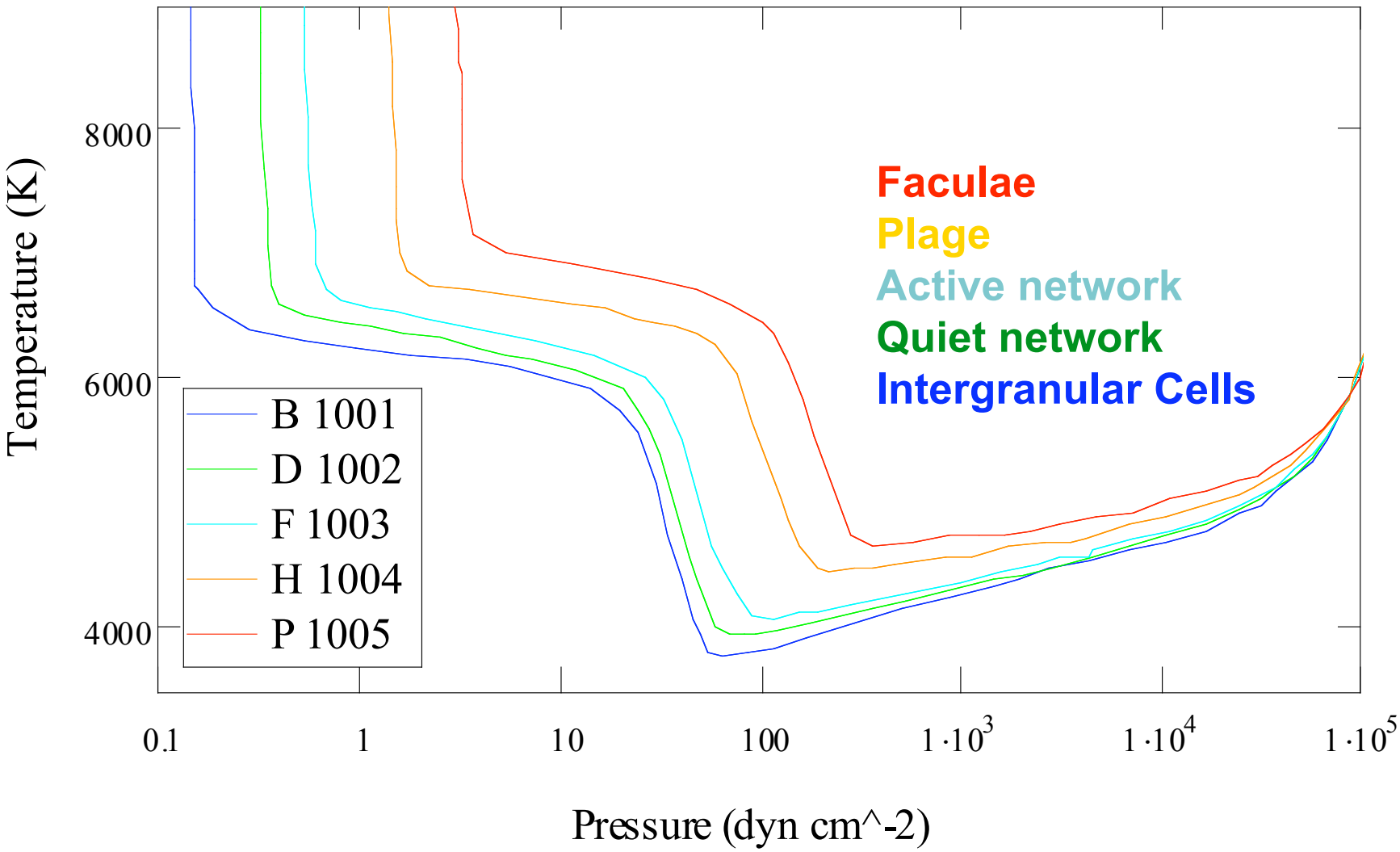
Disk mask on 2005/9/12 obtained from PSPT data, Mauna Loa, Hawaii.

Sunspot Penumbra
Sunspot Umbra
Faculae
Plage
Active network
Quiet network
Intergranular Cells

Contrast of different features on the solar disk

Feature designation	Model index	Feature Description	Pressure at 2×10^5 K (dyne cm^{-2})	Disk Center Contrast in Ca II K MLSO/PSPT
B	1001	Quiet-Sun inter-network	0.235	<1.02
D	1002	Quiet-Sun network lane	0.340	1.02-1.08
F	1003	Enhanced network	0.552	1.08-1.19
H	1004	Plage (that is not facula)	1.00	1.19-1.43
P	1005	Facula (i.e., very bright plage)	1.62	1.43-1.80
S	1006	Sunspot umbra	3.86	...
R	1007	Sunspot penumbra	2.10	...

Fontenla et al., 2009, ApJ,

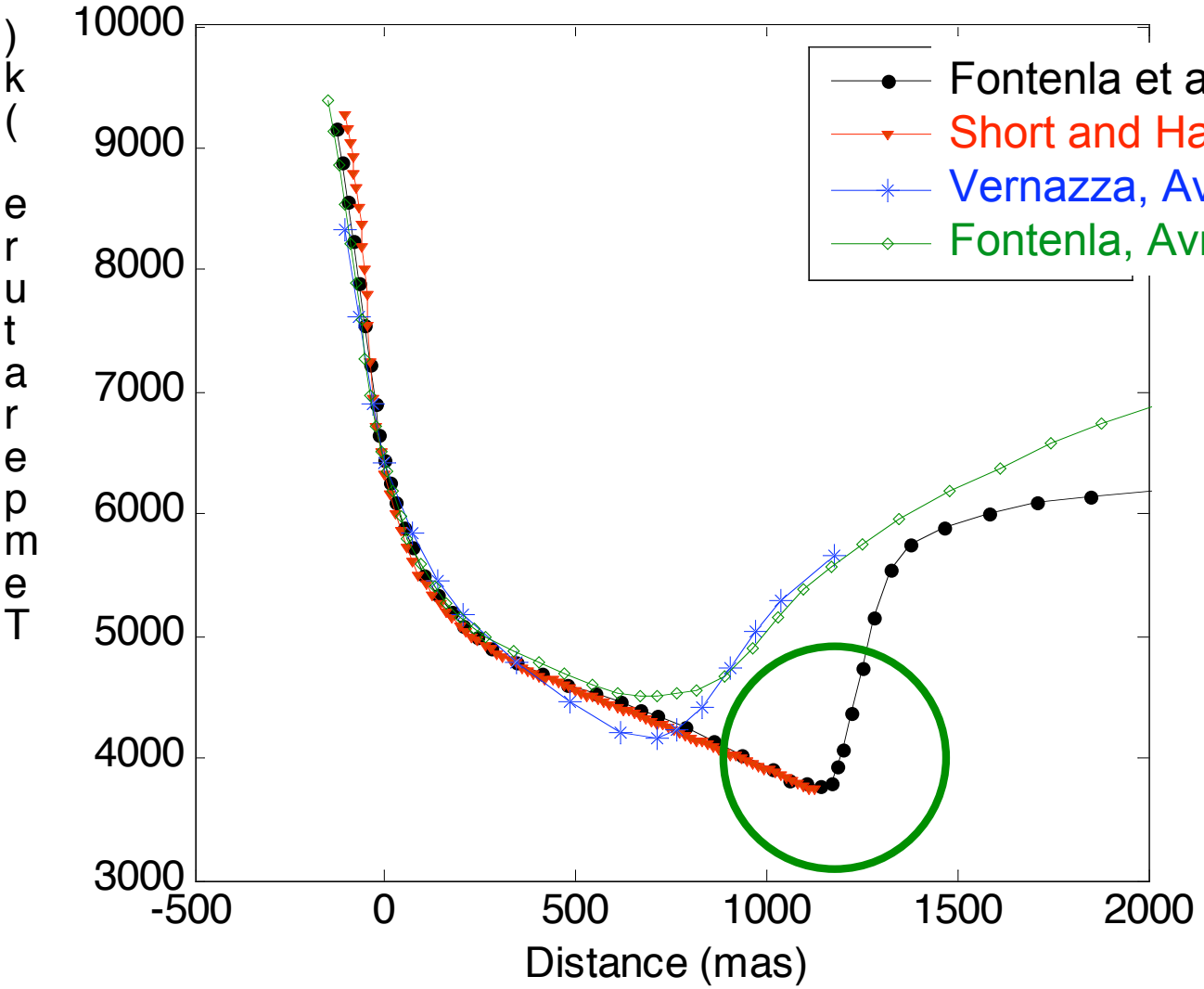


Fontenla et al., 2009, ApJ, in press

Key elements of latest atmosphere structure

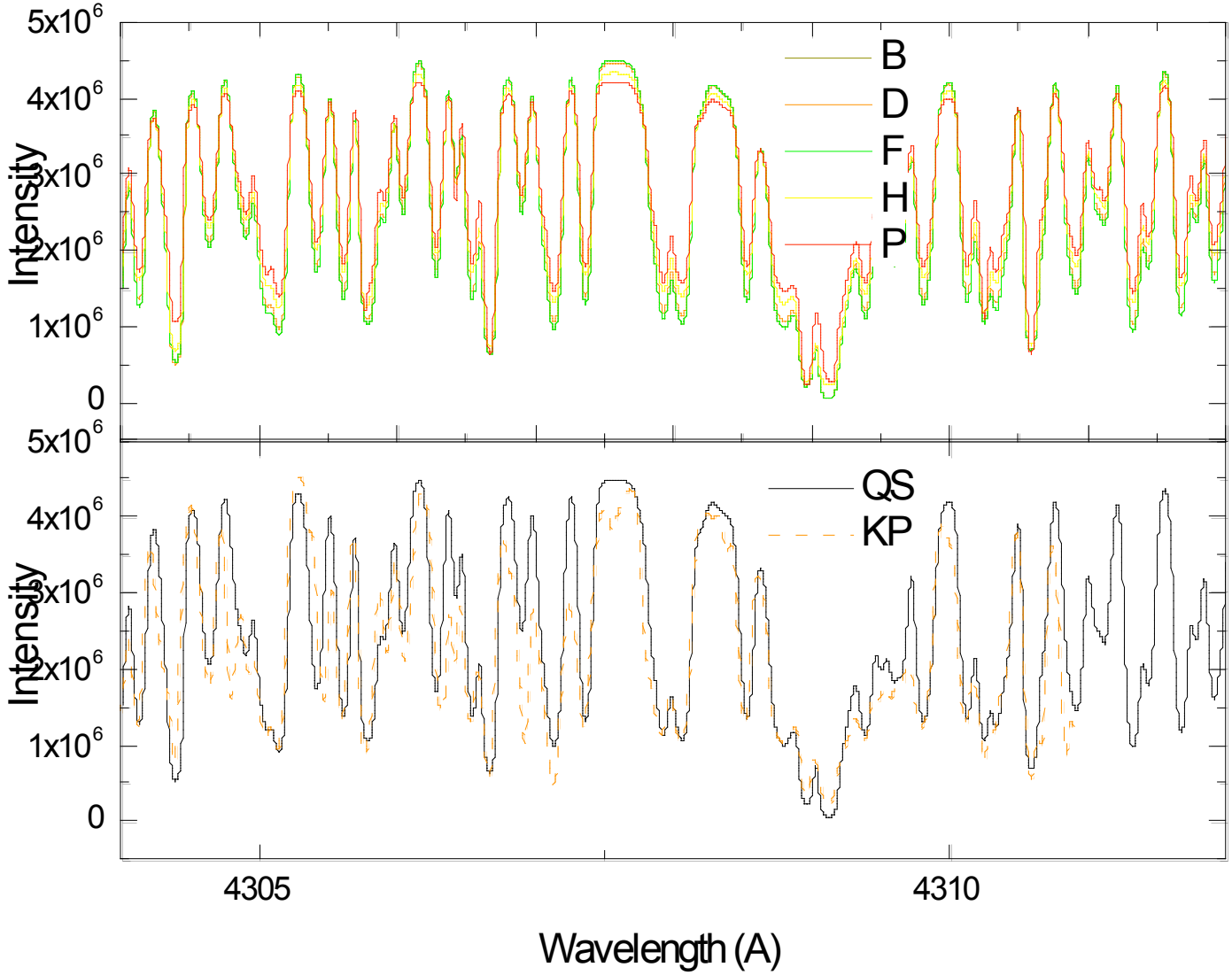
- low temperature minimum at low density
  - in strong NLTE
  - improved agreement of molecular lines (CO, CH)
- Ambipolar diffusion of hydrogen versus protons
  - Increases the amount of neutral hydrogen in lower levels
- Detailed line and continuum opacities

Comparison of different atmosphere strucutres



Low temperature in chromosphere allows the correct formation of molecules such as CO and CH

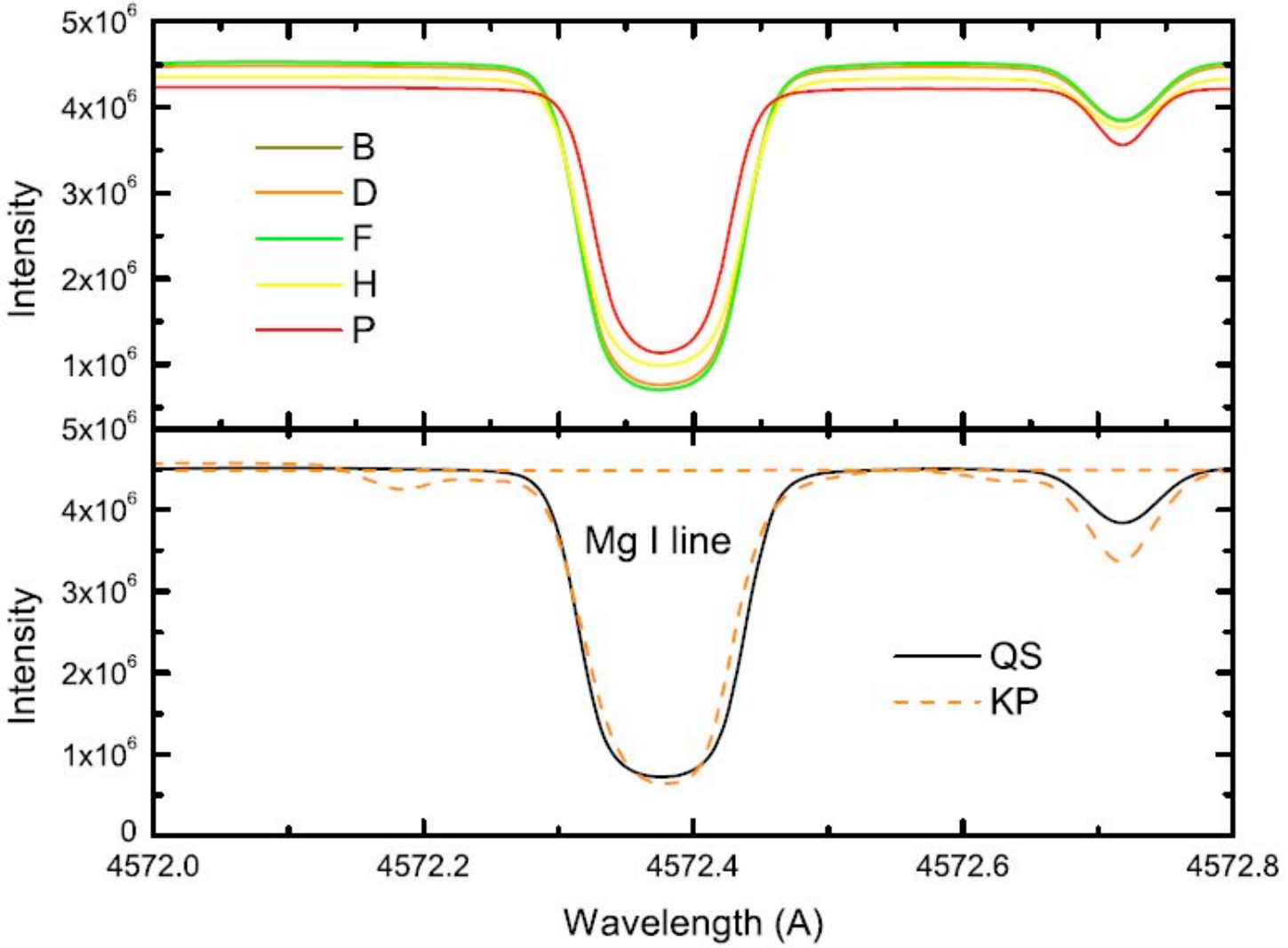
Molecular lines



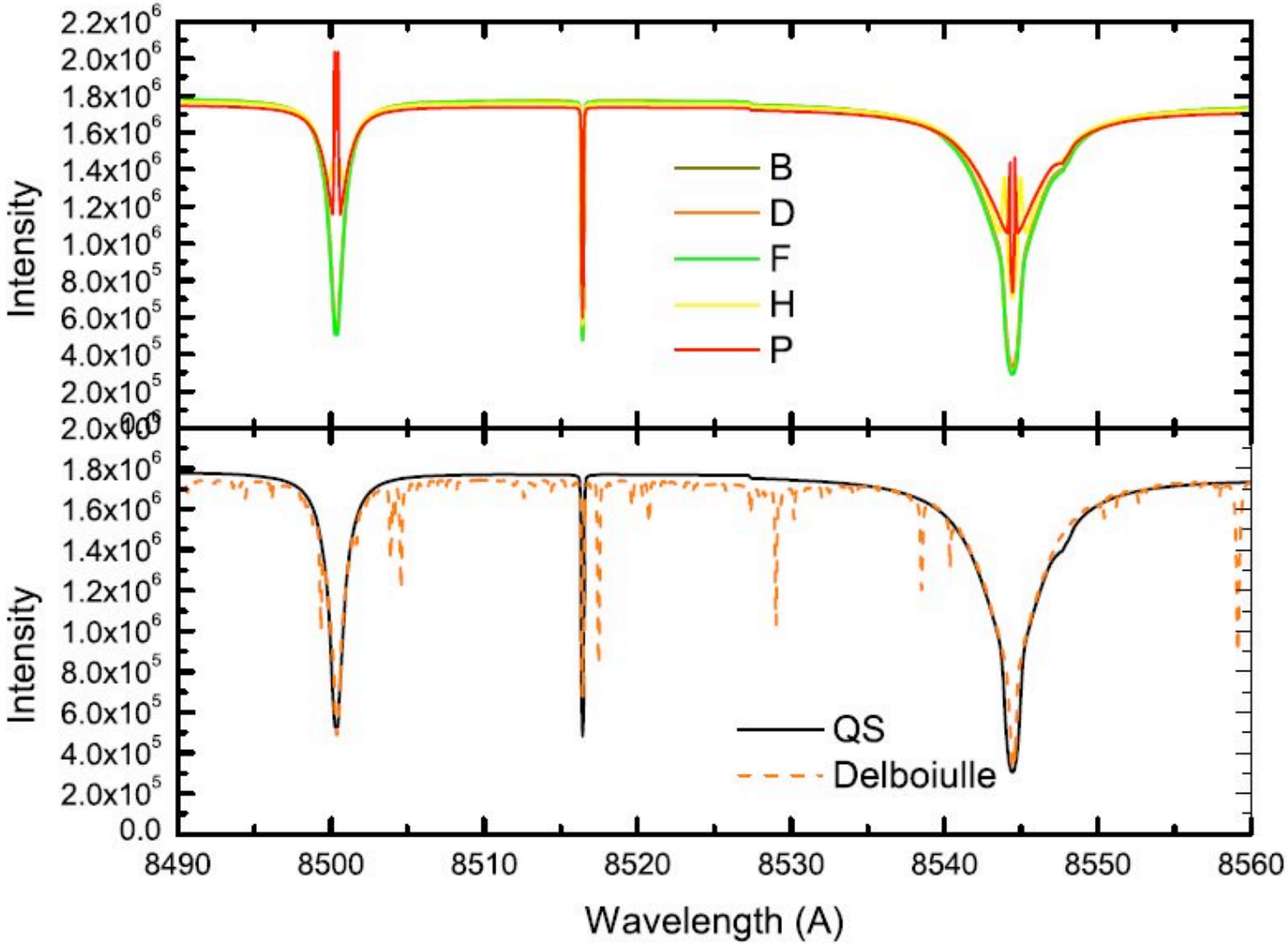
Atoms/Ions in full NLTE

Species	NLTE Levels	Species	NLTE Levels	Species	NLTE Levels
H I	15	...	...	...	...
He I	20	He II	15	...	...
C I	45	C II	27	C III	38
N I	26	N II	33	N III	39
O I	23	O II	31	O III	44
NA I	22	...	...	...	...
MG I	26	MG II	14	MG III	54
AL I	18	AL II	14	Al III	32
SI I	35	SI II	14	SI III	60
S I	20	S II	30	S III	32
CA I	22	CA II	24	...	...
FE I	120	FE II	120	...	...

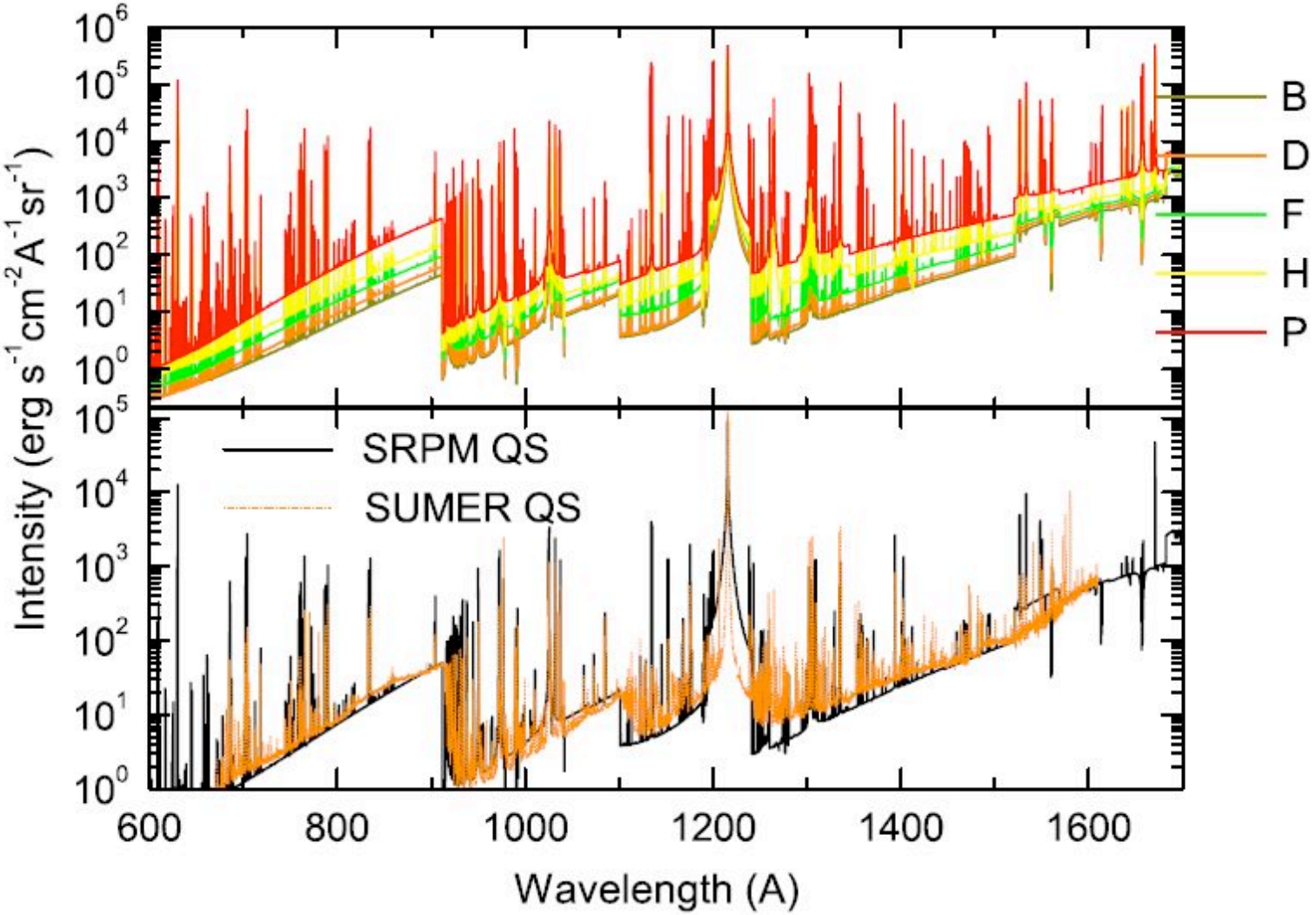
Mg I 4573.77 Å


5x10^6
4x10^6
3x10^6
2x10^6
1x10^6
Intensity
B
D
F
H
P
5x10^6
4x10^6
3x10^6
2x10^6
1x10^6
0
Intensity
Mg I line
QS
KP
4572.0
4572.2
4572.4
4572.6
4572.8
Wavelength (A)

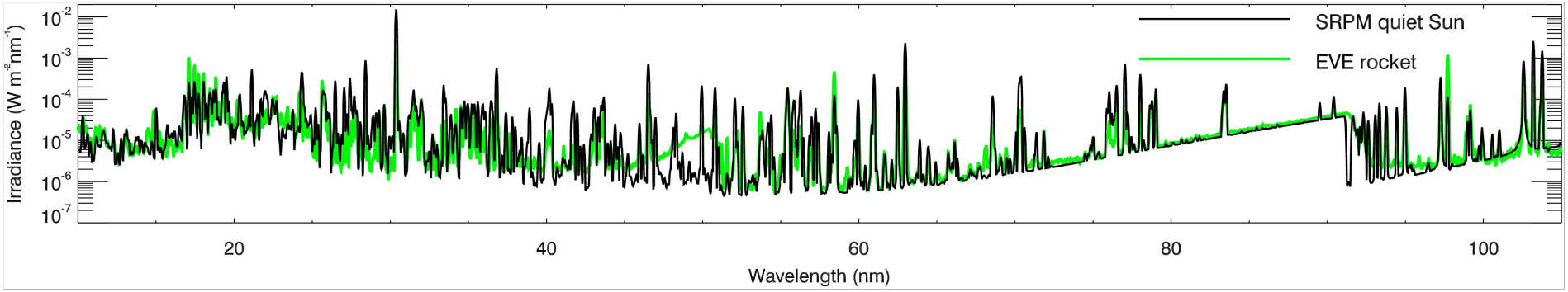
Ca II IR lines



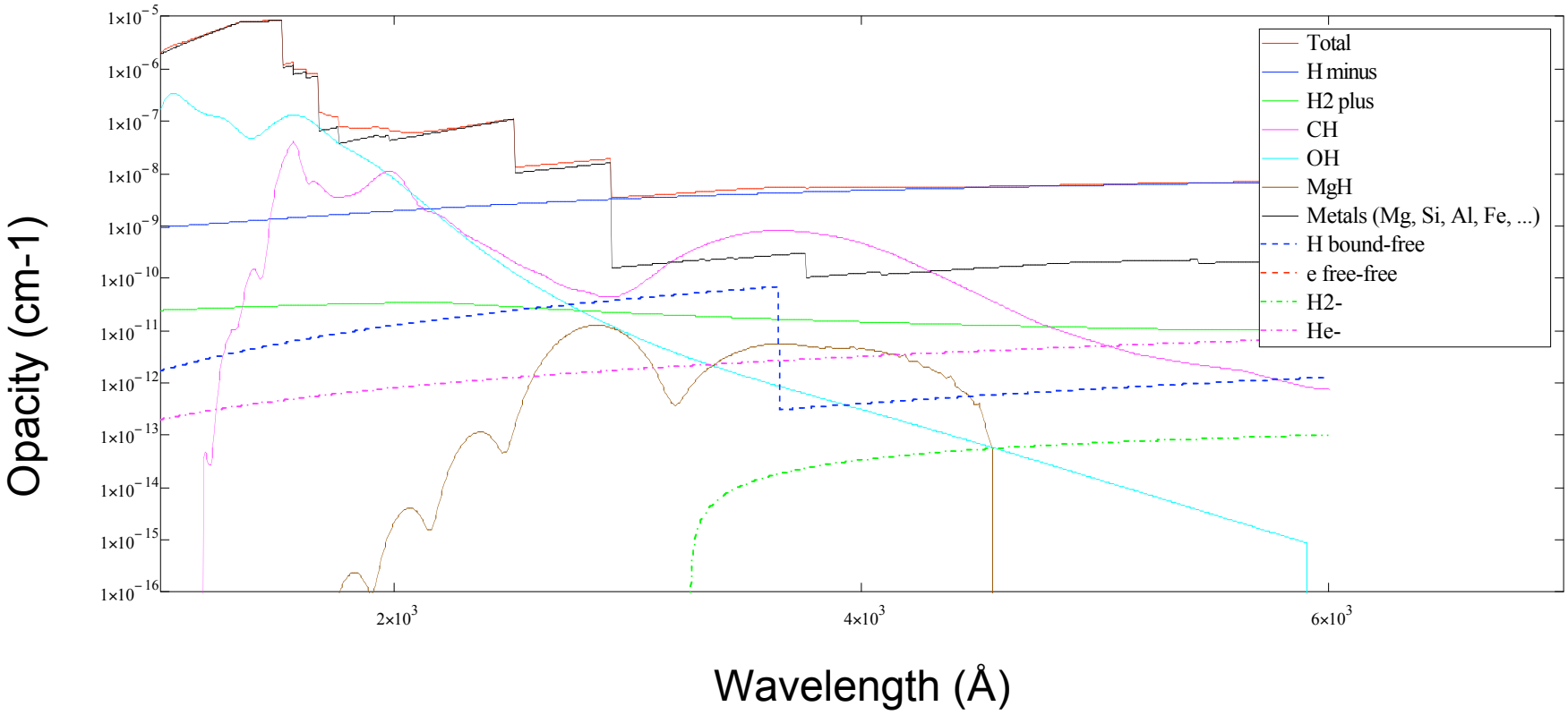
UV Spectra


Intensity (erg s^{-1}cm^{-2}A^{-1}sr^{-1})
10^6
10^5
10^4
10^3
10^2
10^1
10^0
B
D
F
H
P
SRPM QS
SUMER QS
600
800
1000
1200
1400
1600
Wavelength (A)

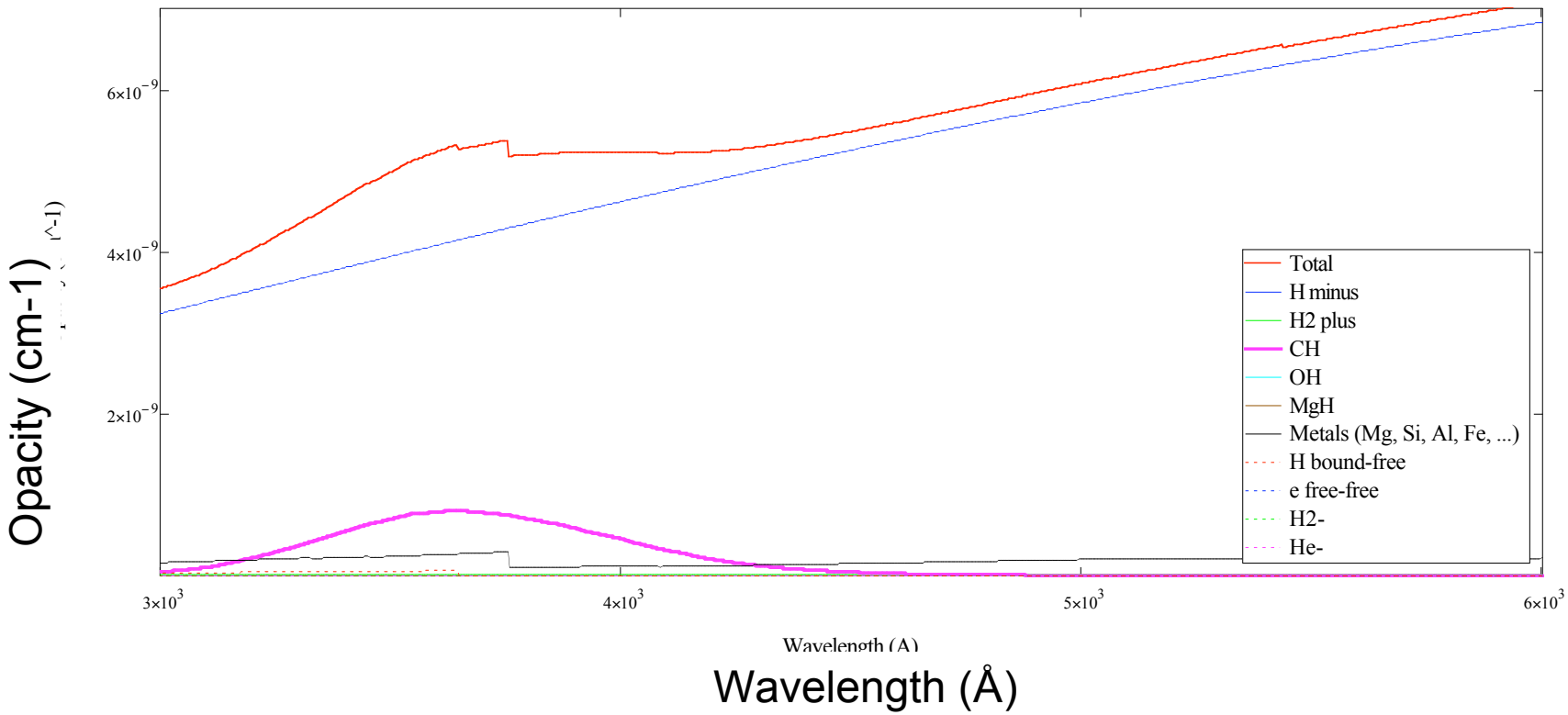
Comparison EVE versus SRPM



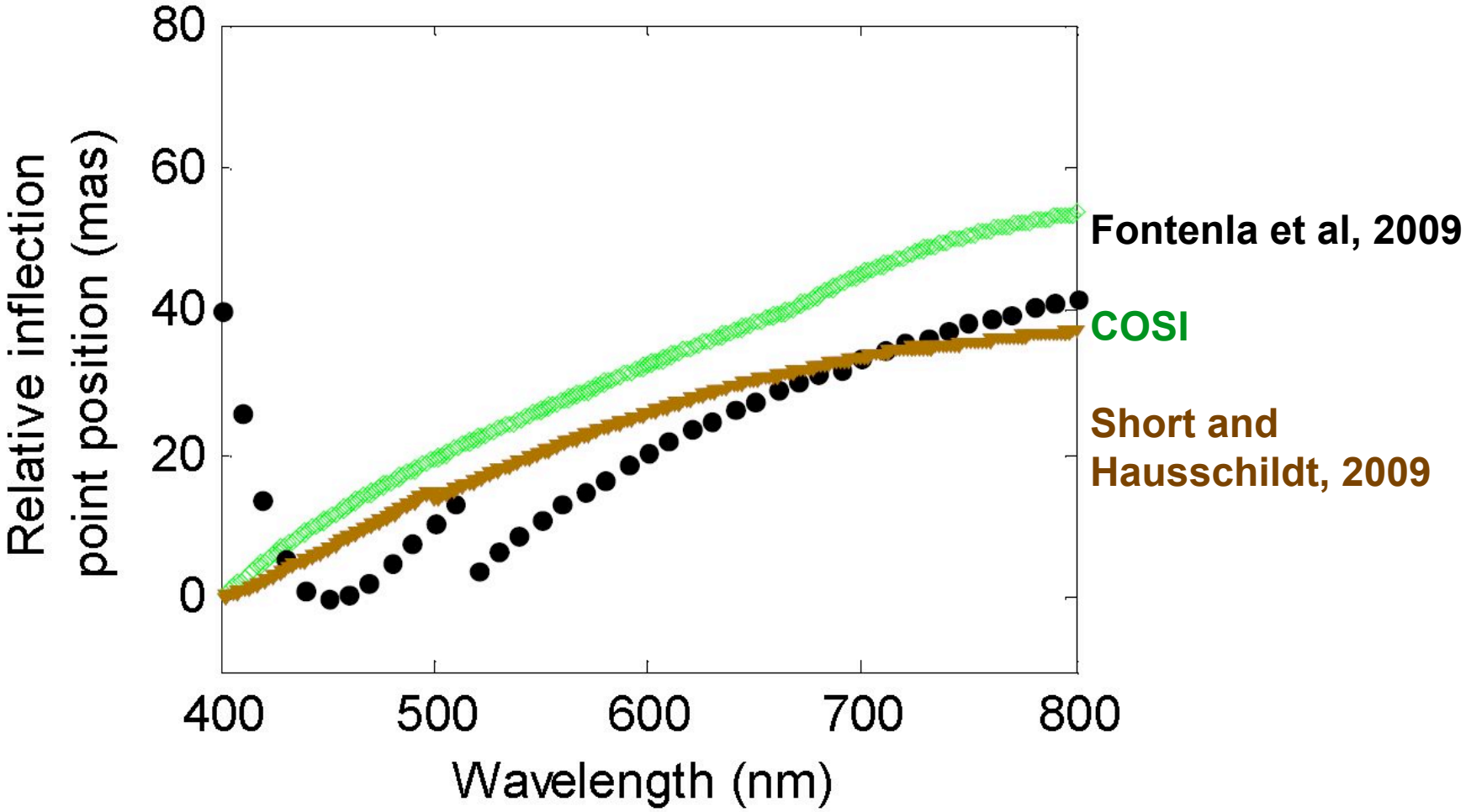
Opacities 2000-6000 A



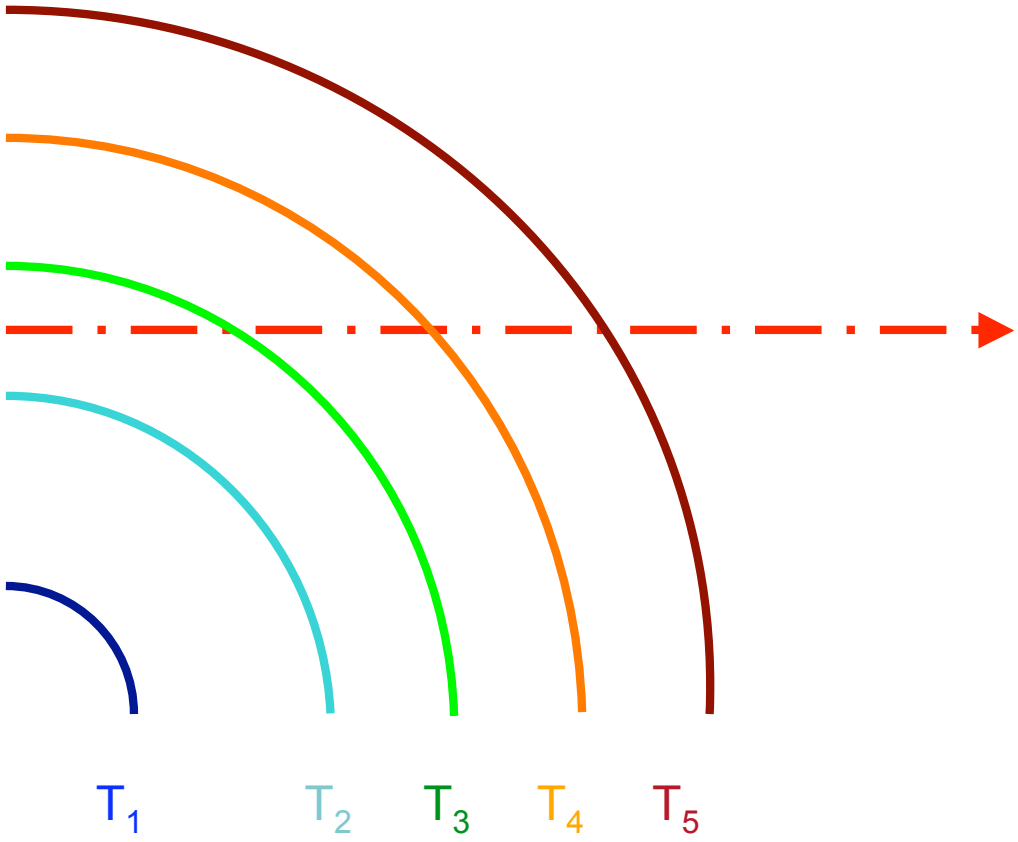
Opacities


Opacity (cm-1)
6×10^-9
4×10^-9
2×10^-9
3×10^3
4×10^3
5×10^3
6×10^3
Wavelength (Å)
Total
H minus
H2 plus
CH
OH
MgH
Metals (Mg, Si, Al, Fe, ...)
H bound-free
e free-free
H2-
He-

Effect of opacities on limb position



Spherical Symmetry



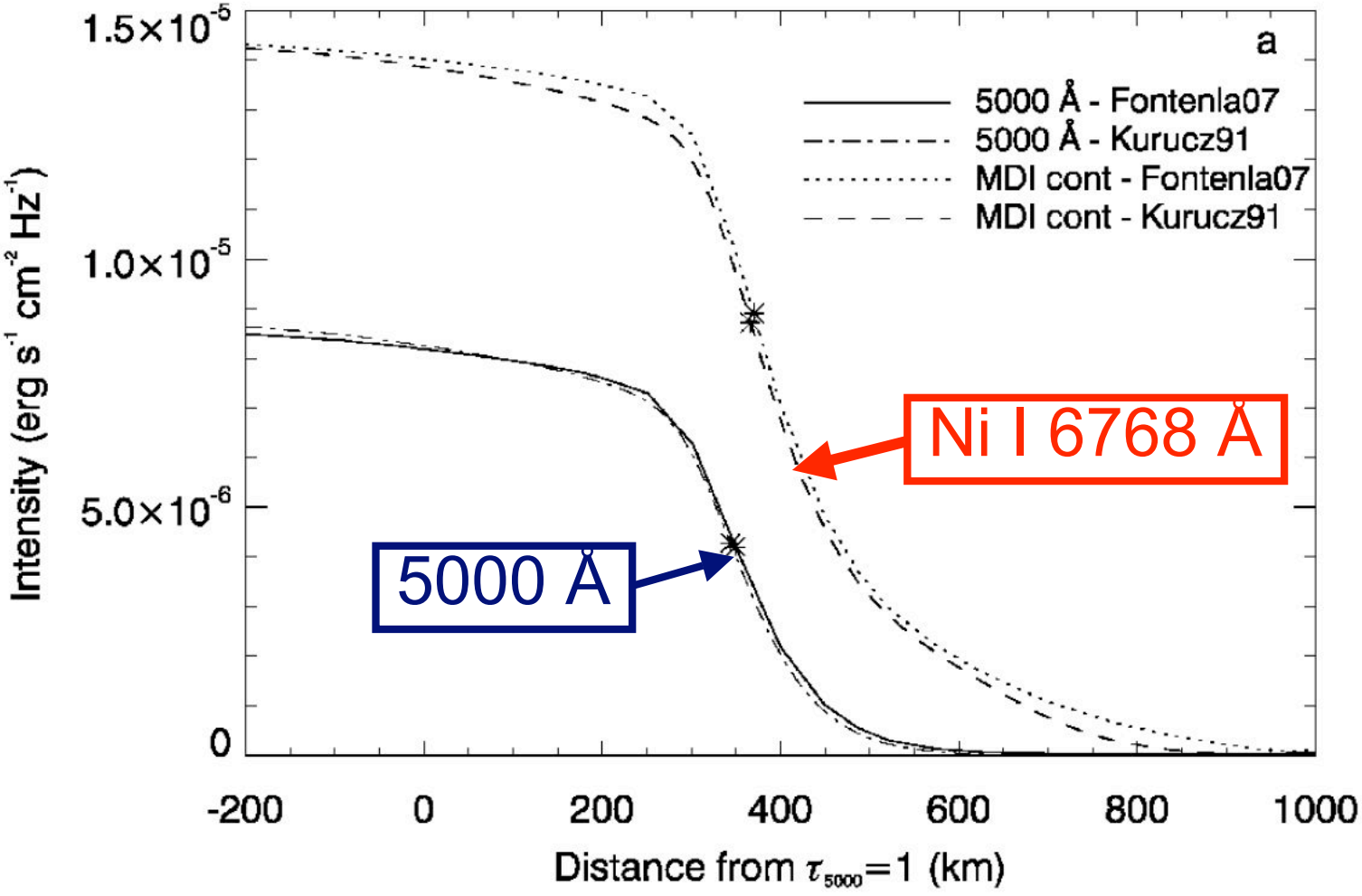
Adopted from Mihalas, 1978

Allows the calculation of intensities at and beyond the limb

(e.g. Haberreiter et al. 2008)

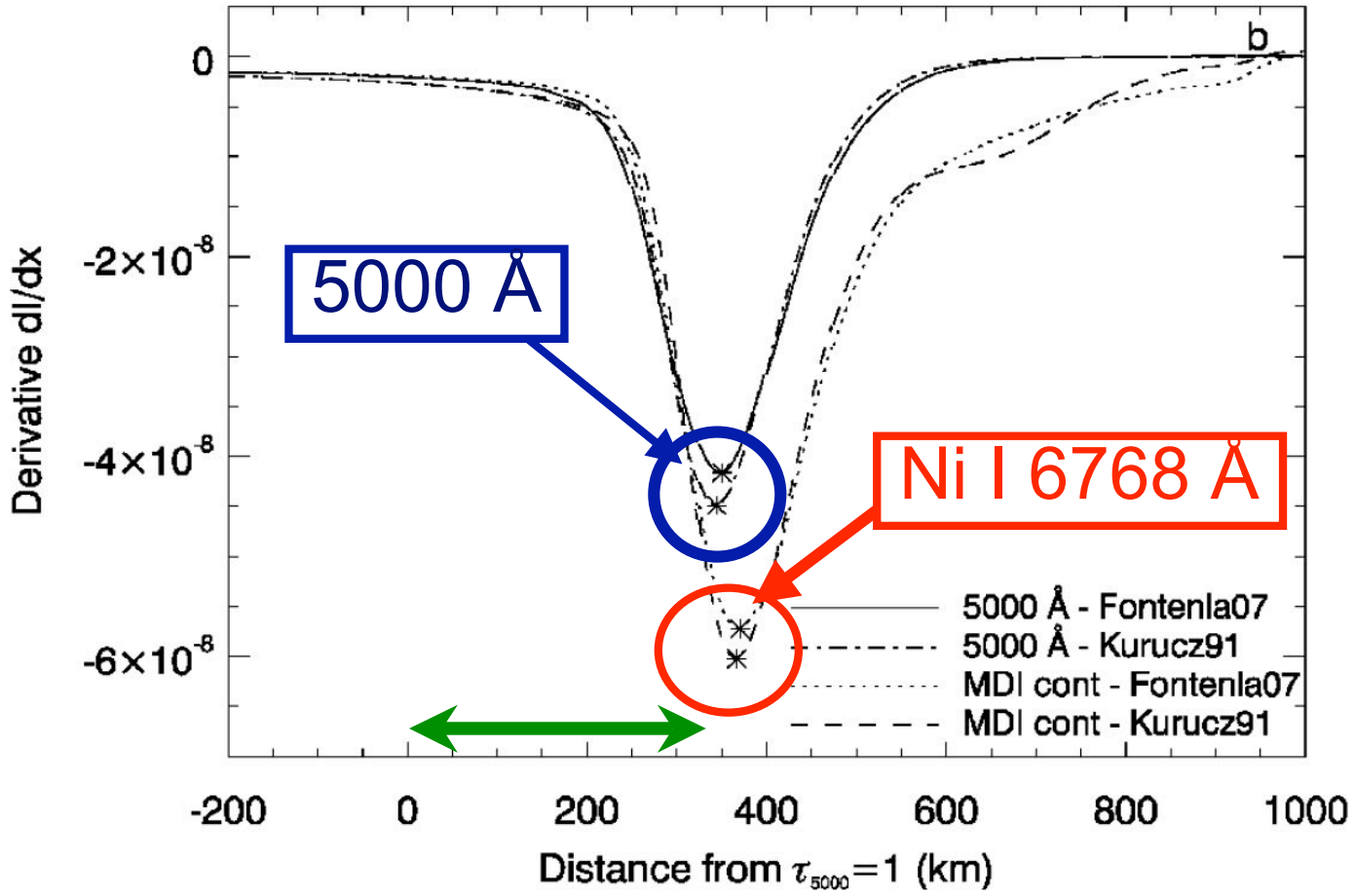
Account for corona over 2 x area of solar disk

Limb profile



Haberreiter et al. 2008, ApJ, L53-56

Derivative of the intensity profile



5000 Å:

z=347 km

Δz=6 km

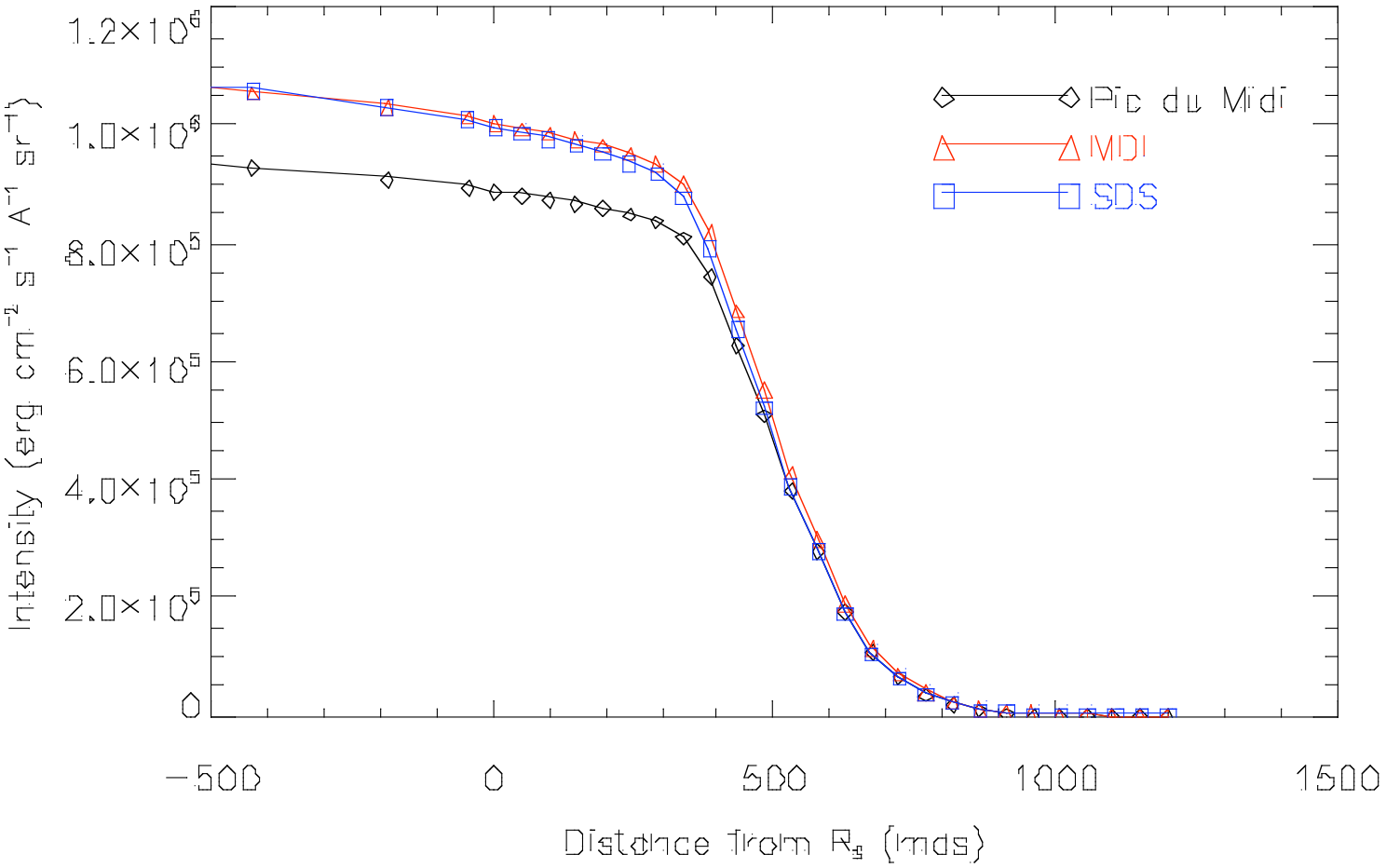
Ni I 6768 Å

z=358 km

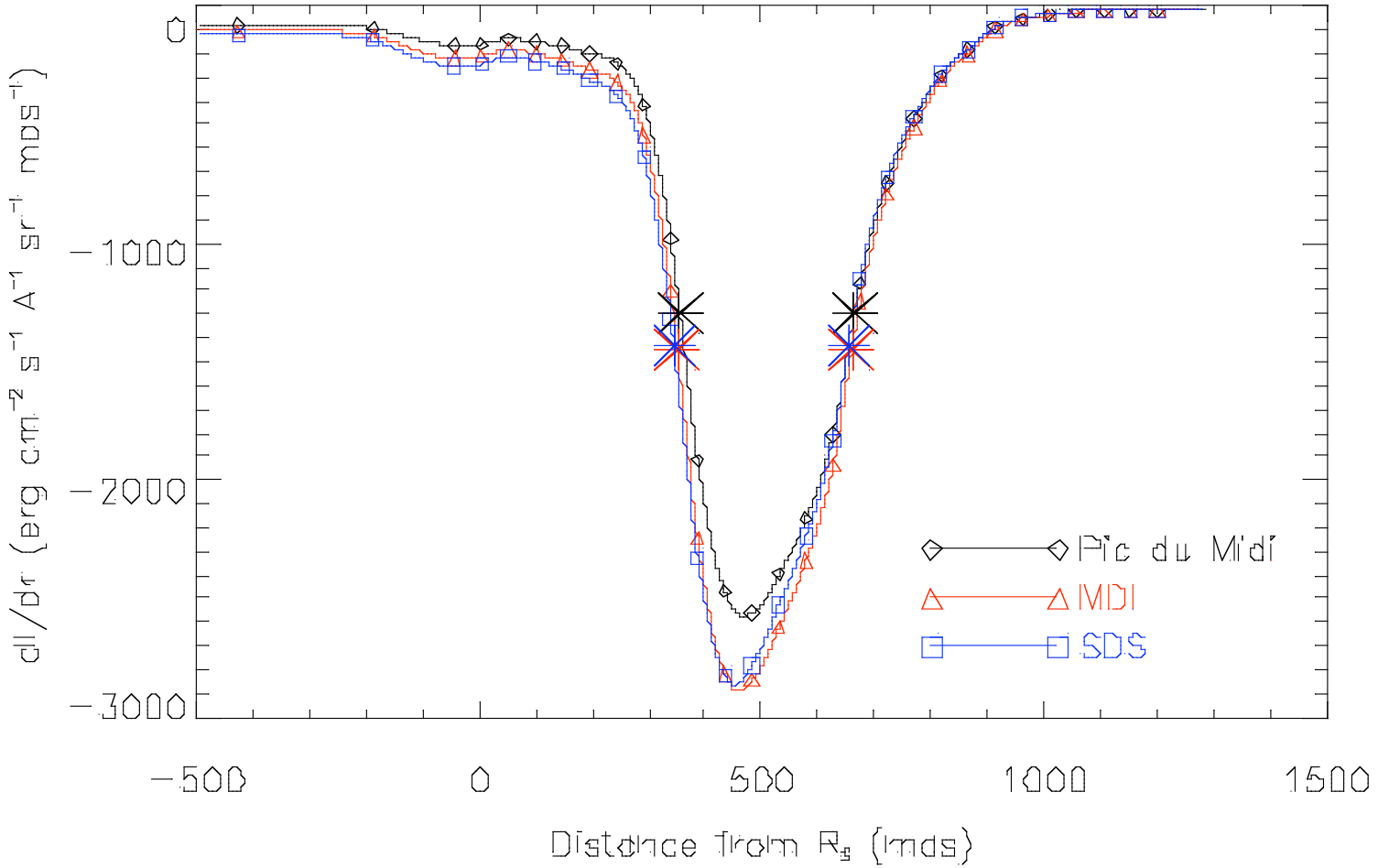
Δz=3 km

Haberreiter et al. 2008, ApJ, L53-56

Limb profile for different instruments



Derivative of dI/dr for different instruments



Conclusion

- Latest Fontenla et al., 2009 atmospheres are very well suited for the calculation of molecular lines
- Detailed continuum and line opacities are included in the calculation
- Different opacities lead to different limb positions
- Complete physics needs to be included for realistic limb modeling