Rosseland
Centre
for Solar
Physics

Stellar Atmosphere Codes I

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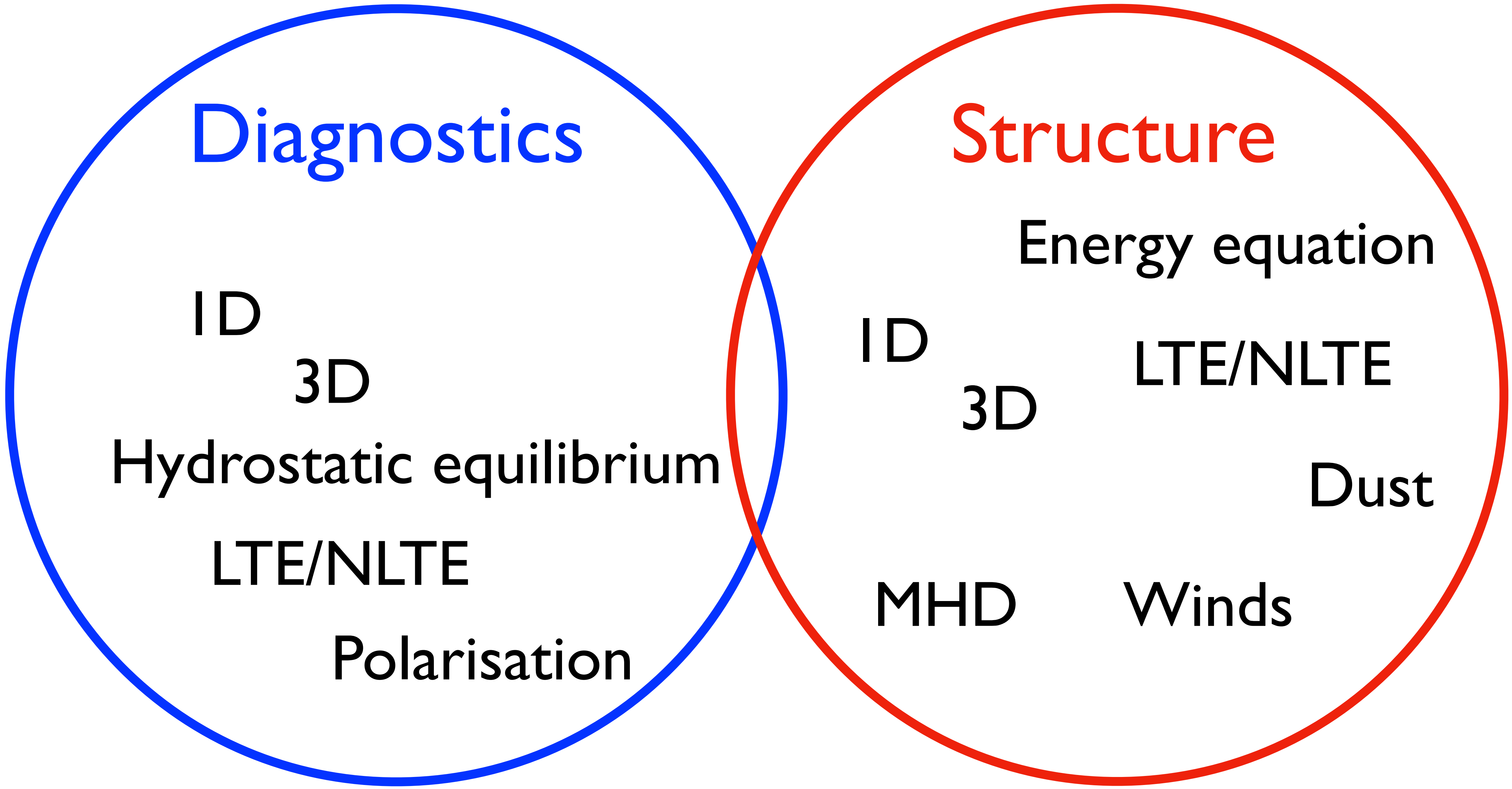
Rosseland Centre for Solar Physics, Univ Oslo
La Laguna, November 14-15 2017

Stellar atmosphere codes



R C S

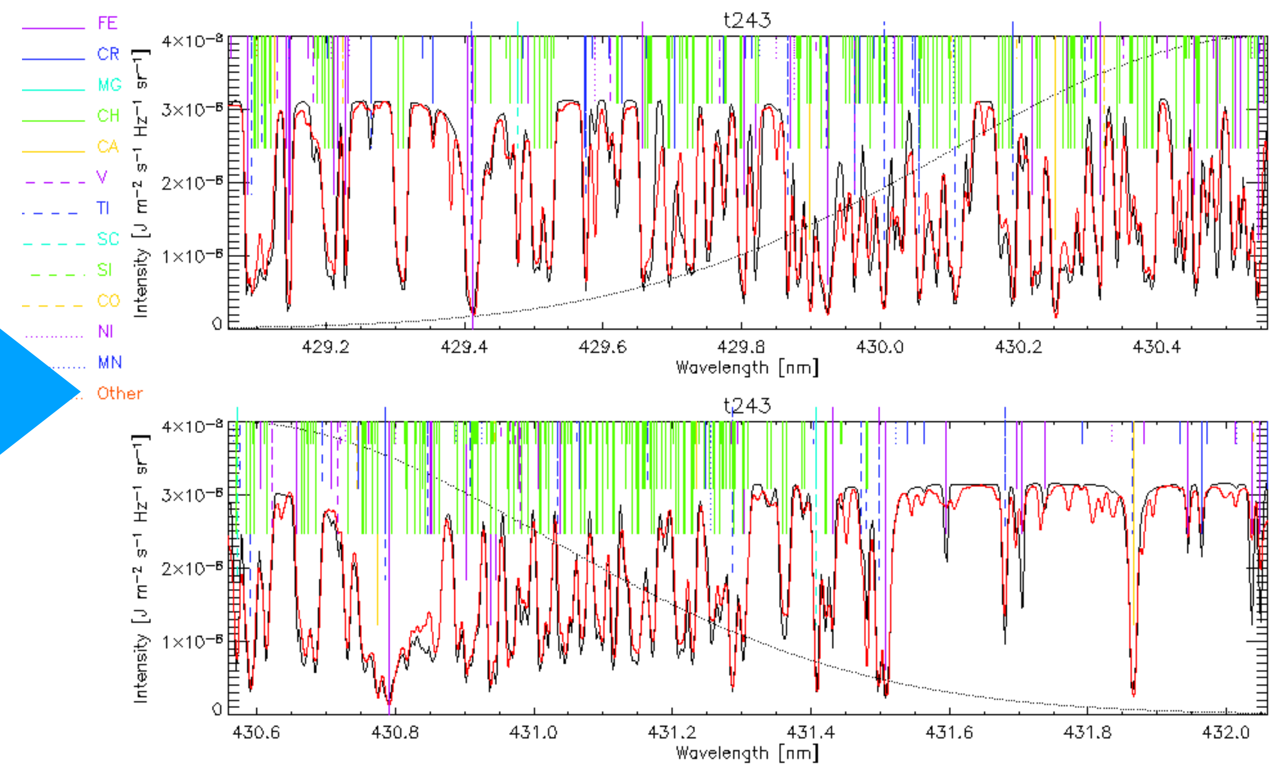
Diagnostic codes

Opacity data

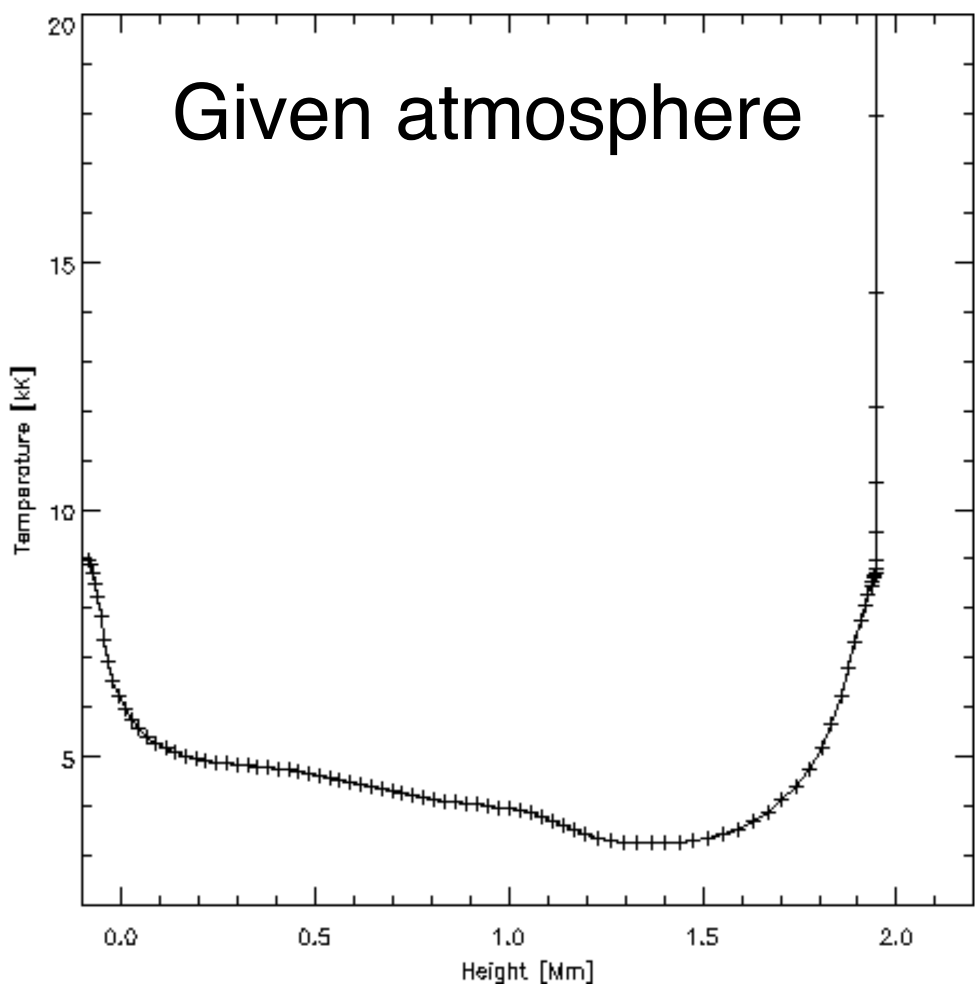
```
CR II
   2          38357.684  4.0
CR II
   2          64061.203  4.0
  3891.156  3889.156  3893.156
   2.0509e-04 2.642e+08  0.95  2.366e-07
...........
```

LTE

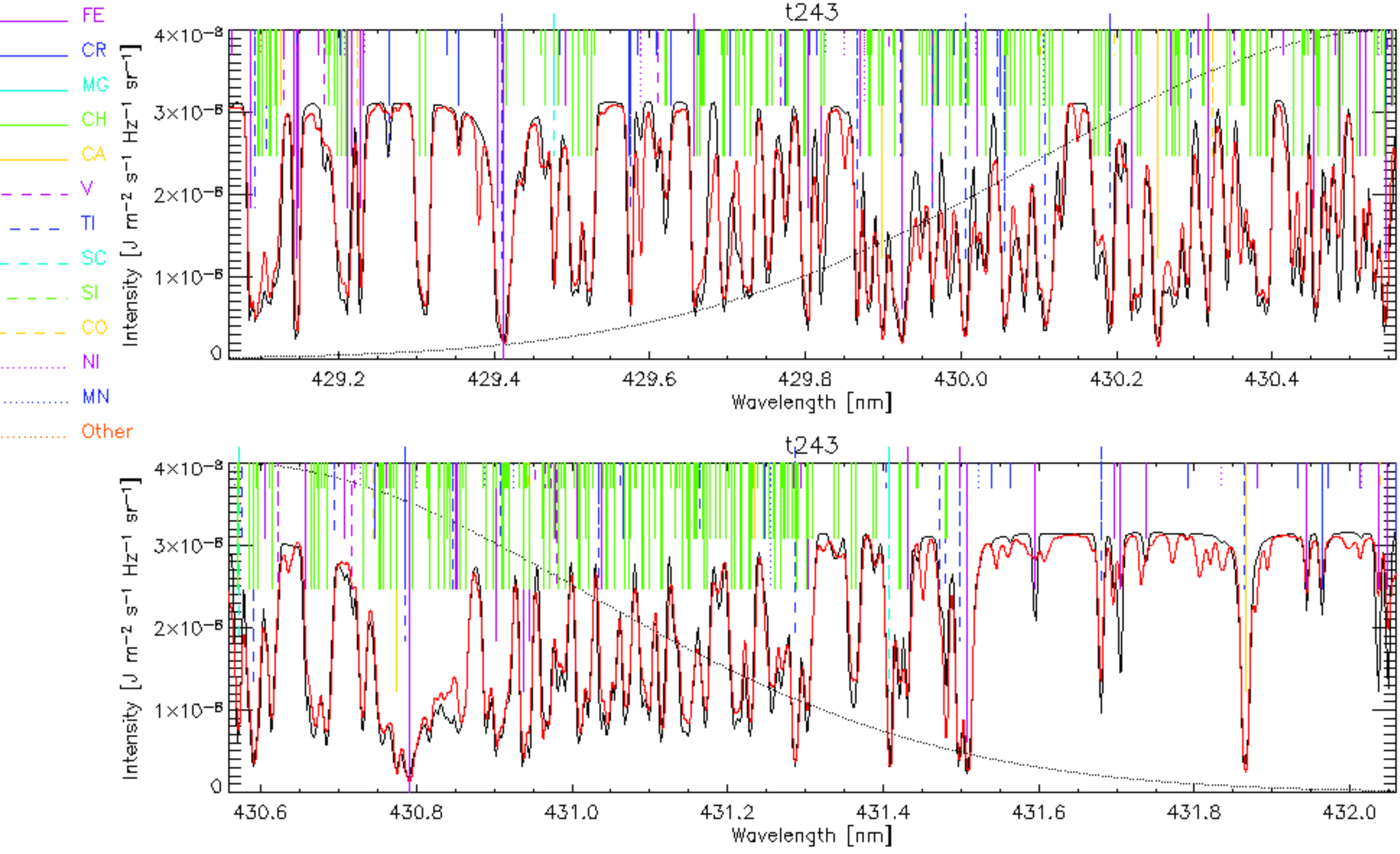
Detailed spectrum



Given atmosphere



R C S



FE
CR
MG
CH
CA
V
TI
SC
SI
CO
NI
MN
Other
t243
Intensity [J m^{-2} s^{-1} Hz^{-1} sr^{-1}]
4×10^{-8}
3×10^{-8}
2×10^{-8}
1×10^{-8}
0
429.2
429.4
429.6
429.8
430.0
430.2
430.4
Wavelength [nm]
t243
Intensity [J m^{-2} s^{-1} Hz^{-1} sr^{-1}]
4×10^{-8}
3×10^{-8}
2×10^{-8}
1×10^{-8}
0
430.6
430.8
431.0
431.2
431.4
431.6
431.8
432.0
Wavelength [nm]

R C S

Diagnostic codes, LTE

- many codes. Input data format. Input data
  - Turbomarcs: MARCS
  - MOOG: ATLASx
  - Synthe: ATLASx
  - Synspec: ATLASx, Tlusty

R C S

SYNSPEC
Version 43

- User's guide
- References
- Synplot
- Convolution (Rotin3)
- Data
- Model atmospheres
- Download ***Synspec***

- ***Tlusty***

Synspec's Home

Contact Us

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Last update: October 5, 2005

Synspec

Welcome to Synspec's Home Page!

Ivan Hubeny & Thierry Lanz

University Of Arizona Steward Observatory

University of Maryland Astronomy

A user-oriented package for modeling stellar atmospheres and for stellar spectroscopic diagnostics

---

Synspec is a general spectrum synthesis program. It assumes an existing model atmosphere, calculated previously with Tlusty or taken from the literature, for instance from the Kurucz grid of models. The opacity sources (continua, atomic and molecular lines) are fully specified by the user. An arbitrary stellar rotation and instrumental profile can be applied to the synthetic spectrum.

Synplot is a user-friendly IDL wrapper around Synspec. Synplot is keyword-driven and incorporates all the necessary plotting resources for spectral analyses.

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http://nova.astro.umd.edu/Synspec43/synspec.html

non-LTE

R C S

Diagnostic codes, NLTE

- Linear-A, Linear-B, Pandora,…
- ✚ MULTI (Carlsson 1986)
- MUGA (Fabiani-Bendicho, Trujillo-Bueno 1995…)
- ✚ RH (Uitenbroek 2001)
- Phoenix (Hauschildt, Baron)
- PORTA (Stepan, Trujillo-Bueno 2013)
- ✚ NICOLE (Socas-Navarro et al 2015)
- (Detail/Surface, CMFGEN, FASTWIND, PoWR, Tlusty, WM-basic)

Diagnostic codes, NLTE

- Linear-A, Linear-B, Pandora,…
- MULTI (Carlsson 1986)
- MUGA (Fabiani-Bendicho, Trujillo-Bueno 1995…)
- RH (Uitenbroek 2001) PRD, IQUV
- Phoenix (Hauschildt, Baron) extensive model atoms
- PORTA (Stepan, Trujillo-Bueno 2013)
- NICOLE (Socas-Navarro et al 2015)
- (Detail/Surface, CMFGEN, FASTWIND, PoWR, Tlusty, WM-basic)

MULTI

R C S

Background

- Problem: non-LTE spectrum from given atmosphere
- Computer: serial, few MB RAM, 20 MHz
- Language: Fortran-77

CPU speed

Table 1. CPU-usage. VAX-11/750

	Ca %	H %	Fe %
Initializations	9	9	3
Background opacities	11	13	4
Voigt profiles	2	1	1
Error calculation	36	30	15
Set up of matrices	20	28	15
Solving matrix equations	22	19	62
Total (seconds)	63	127	335

Portability

Table 2. CPU speed relative to VAX-11/750, Ca II problem

a) 45 depth-points

Computer, operating system	total	EQSYST
Cray 1A	36.3	48.2
Amdahl VP-1100	25.0	64.0
Allient FX/8 2 CE, UNIX	5.8	10.8
Allient FX/8 1 CE, UNIX	4.8	6.0
FPS-164	4.5	6.7
ELXSI, EMBOS	3.9	3.6
NorskData 570/CX, SINTRAN III		
with array instructions in EQSYST	3.8	6.6
Gould Concept 32/8750, MPX, FPA	3.5	2.8
NorskData 570/CX, SINTRAN III	3.4	2.5
Cyber 170/835, NOS	2.6	2.0
VAX-11/780, VMS 4.2, FPA	1.5	1.2
Gould Concept 32/67, MPX, FPA	1.2	0.8
MicroVAX II, VMS 4.1, FPA	1.1	1.1
VAX-11/750, VMS 4.2, FPA	1.0	1.0
VAX-11/780, UNIX 4.2BSD, FPA	0.6	0.7
NorskData 530/CX, SINTRAN III	0.6	0.4
HP-9000, UNIX, FPA	0.5	0.5

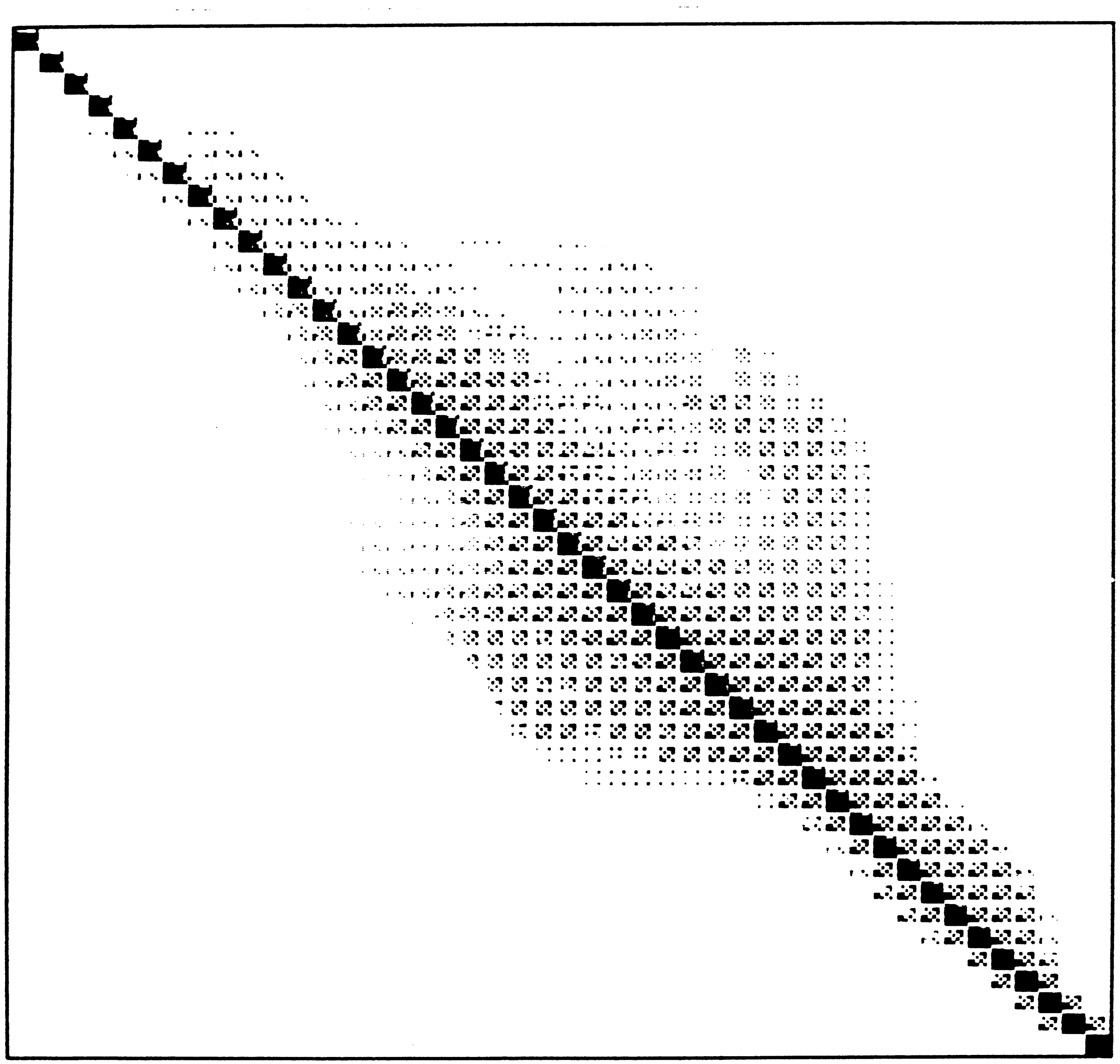
Macbook Pro 2.8 GHz i7 (2015): 0.08s, speedup 790

MULTI

http://folk.uio.no/matsc/mul23

- 1D
- Statistical equilibrium
- given atmosphere {T, Ne, Vz, Vmic}(z)
- one element at a time
- continuum opacity in LTE
- Complete Redistribution
- Hydrostatic equilibrium can be solved for

Scharmer (global) or diagonal (local) operator



Scharmer (1981) operator
Ca II 5 levels+continuum, 45 depth points

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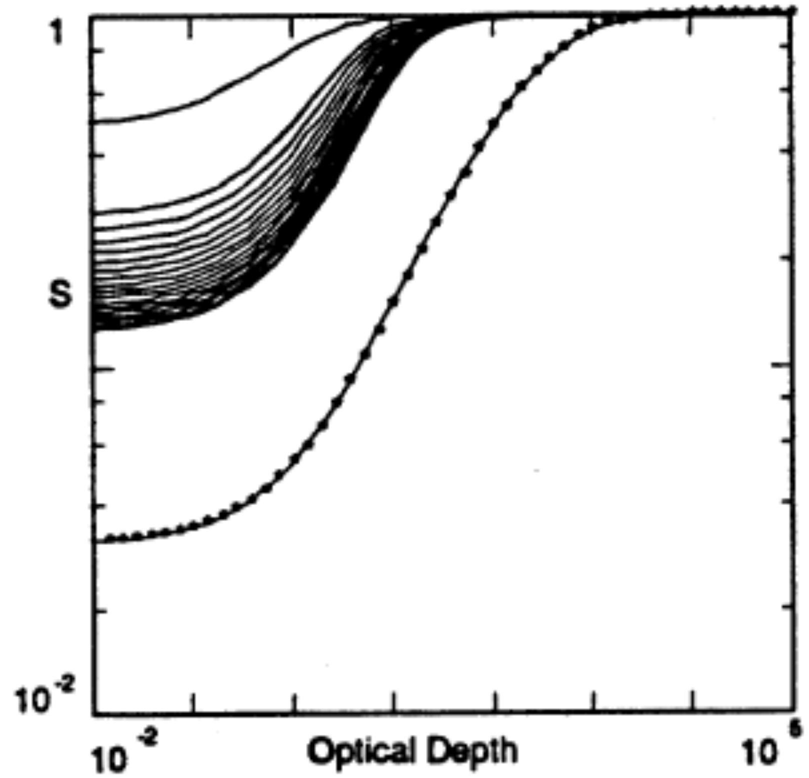
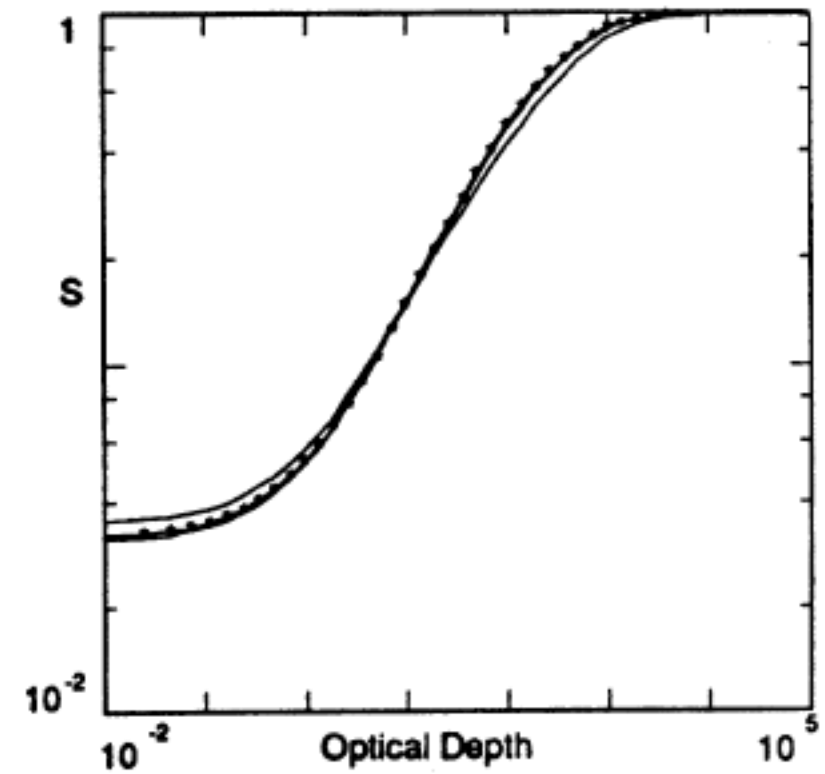
Convergence properties

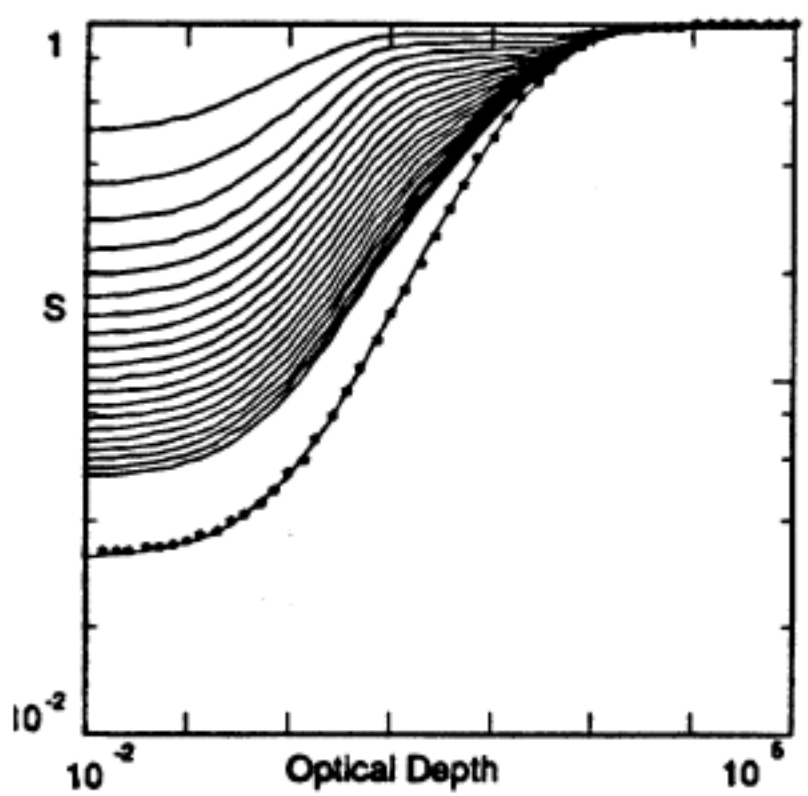
Lambda iteration



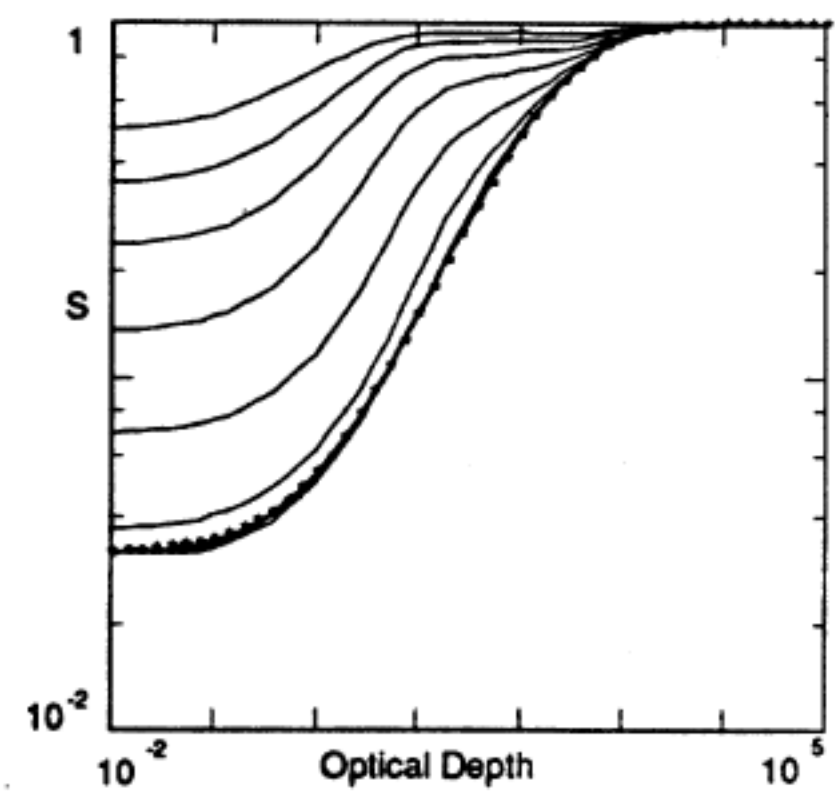
Scharmer operator



Local operator



Local + acceleration



MULTI documentation

in http://folk.uio.no/matsc/mul23

multi_manual.pdf	quick start manual
report33.pdf	version 1.0 documentation
mul23.pdf	version 2.3 documentation
idldoc.pdf	IDL routines documentation
multi_exercises.pdf	exercises

MULTI

Input files

ATMOS	atmospheric structure
DSCALE	depth discretization
ABUND	abundances
ABSDAT	background opacities
ATOM	atomic data
INPUT	switches, run-parameters

Output

IDL files

JOBLOG

OUT

R C S

ATMOS

```
  VAL3C
  MASS SCALE
*
* LG G
  4.44
*
* NDEP
  52
*
*LG CMASS          TEMPERATURE       NE           V              VTURB
  -5.279262E+00   4.470000E+05   1.205000E+09   0.             1.128000E+01
  -5.270430E+00   1.410000E+05   3.839000E+09   0.             9.870000E+00
  -5.269783E+00   8.910000E+04   5.961000E+09   0.             9.820000E+00
  -5.268492E+00   5.000000E+04   9.993000E+09   0.             9.760000E+00
...
*
*  HYDROGEN POPULATIONS
*  NH(1)        NH(2)        NH(3)        NH(4)        NH(5)        NP
   2.3841E+03   7.9839E-04   2.0919E-04   2.3110E-04   2.9470E-04   1.0030E+09
   5.3401E+04   1.8790E-02   7.4560E-03   8.1751E-03   1.0430E-02   3.1990E+09
   2.4030E+05   7.5740E-02   2.9400E-02   3.1550E-02   4.0101E-02   5.0310E+09
...
```

R C S

DSCALE

```
* DEPTH SCALE FROM DSCAL2
 DSCAL2 ON equidistant
 MASS SCALE
* NDEP    lg(Tau_500[1])
  80      -6.672232
      -5.225000
      -5.213486
...
```

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ABUND

```
H    12.00     abundances from
HE   10.93     Asplund, Grevesse, Sauval, Scott 2009, ARAA 47, 481
SI    7.51
MG    7.60
AL    6.45
FE    7.50
C     8.43
NA    6.24
S     7.12
K     5.03
CA    6.34
NI    6.22
CR    5.64
N     7.83
O     8.69
NE    7.93
SC    3.15
TI    4.95
V     3.93
MN    5.43
CO    4.99
```

ABSDAT

```
         21
H  HE C  N  O  NE NA MG AL SI S  K  CA SC TI V  CR MN FE CO NI
     1.008     4.003     12.01     14.01     16.00     20.18
     23.00     24.32     26.97     28.06     32.06     39.10
     40.08     45.0      47.9      50.9      52.01     54.9
     55.85     58.9      58.69
    2    3    4    4    4    4    4    4    4    4    4    4
    4    4    4    4    4    4    4    4    4
    2    1
H I
13.595   2 11.0    2
H I
...
/CA II 3P6 4S 2SE      CA III GROUND TERM   P.JUDGE / COMPILATION
 2              0.000    2.0
   ILOGL=1   KVADL=0   MINEX=0   MAXEX=0  NLATB= 11
      510.      600.      750.      850.      950.     1000.
     1020.     1026.     1030.     1035.     1045.
   ILOGT=0   KVADT=0   MINET=0   MAXET=0  NTETB=  1   ITETA=0
 1.557E-19 1.836E-19 2.101E-19 2.183E-19 2.142E-19 2.122E-19
 2.101E-19 2.081E-19 2.060E-19 2.060E-19 2.040E-19
```

ATOM

```
CA II
* ABUND   AWGT
  6.36   40.08
*NK NLINE NCONT NRFIX
  6   5    5     0
*   E          G          LABEL                  ION
   0.00000   2.00000   'CA II 3P6 4S 2SE     '   2
 13650.248   4.00000   'CA II 3P6 3D 2DE 3/2'   2
 13710.900   6.00000   'CA II 3P6 3D 2DE 5/2'   2
 25191.535   2.00000   'CA II 3P6 4P 2PO 1/2'   2
 25414.465   4.00000   'CA II 3P6 4P 2PO 3/2'   2
 95785.470   1.00000   'CA III GROUND TERM  '   3
* J  I      F        NQ  QMAX  Q0 IW    GA       GVW      GS
  4  1  3.1600E-01 101  300.  3. 0  1.42E08  234.223  3.0E-06
  5  1  6.3700E-01 101  300.  3. 0  1.46E08  234.223  3.0E-06
  4  2  4.7300E-02 101  150.  1. 0  1.42E08    2.04   3.0E-06
  5  2  9.6000E-03 101  150.  1. 0  1.46E08    2.01   3.0E-06
  5  3  5.7400E-02 101  150.  1. 0  1.46E08    2.01   3.0E-06
* UP  LO   F        NQ   QMAX    Q0
   6  1  2.036E-19  5   -1.     0.0
  1044.2   2.0360E-19
   911.7   2.1400E-19
   850.0   2.1720E-19
   750.0   2.1030E-19
   600.0   1.8200E-19
*
...
 GENCOL
 TEMP
  7     2000.     3000.     6000.     12000.     24000.     48000.     96000.
OHMEGA
  2  1  5.60e+00  5.60e+00  5.60e+00  5.60e+00  5.60e+00  5.60e+00  5.60e+00
OHMEGA
...
```

INPUT

```
DIFF=2.0,ELIM1=0.1,ELIM2=0.001,QNORM=12.85,THIN=0.1,
IATOM2=0,ICONV=1,IHSE=0,ILAMBD=2,IOPAC=1,ISTART=1,ISUM=0,
ITMAX=40,ITRAN=0,NMU=5,
IWABND=0,IWATMS=0,IWATOM=0,IWCHAN=0,IWDAMP=0,IWEMAX=1,IWEQW=0,
IWEVEC=0,IWHEAD=0,IWHSE=0,IWLGMX=1,IWLINE=0,IWLTE=0,IWN=0,IWNIIT=0,
IWOPAC=0,IWRAD=0,IWRATE=0,IWSTRT=0,IWTAUQ=0,IWTEST=0,IWWMAT=0,
IWJFIX=0,IWARN=0,IOPACL=0,ISCAT=0,INCRAD=0,INGACC=0,ICRSW=0,
IOSMET=0,EOSMET=0.5,
IDL1=1,IDLNY=1,IDLCNT=1,IDLOPC=1
```

R C S

INPUT

```
DIFF=2.0,ELIM1=0.1,ELIM2=0.001,QNORM=12.85,THIN=0.1,
IATOM2=0,ICONV=1,IHSE=0,ILAMBD=2,IOPAC=1,ISTART=1,ISUM=0,
ITMAX=40,ITRAN=0,NMU=5,
IWABND=0,IWATMS=0,IWATOM=0,IWCHAN=0,IWDAMP=0,IWEMAX=1,IWEQW=0,
IWEVEC=0,IWHEAD=0,IWHSE=0,IWLGMX=1,IWLINE=0,IWLTE=0,IWN=0,IWNIIT=0,
IWOPAC=0,IWRAD=0,IWRATE=0,IWSTRT=0,IWTAUQ=0,IWTEST=0,IWWMAT=0,
IWJFIX=0,IWARN=0,IOPACL=0,ISCAT=0,INCRAD=0,INGACC=0,ICRSW=0,
IOSMET=0,EOSMET=0.5,
IDL1=1,IDLNY=1,IDLCNT=1,IDLOPC=1
```

R C S

INPUT

```
DIFF=2.0,ELIM1=0.1,ELIM2=0.001,QNORM=12.85,THIN=0.1,
IATOM2=0,ICONV=1,IHSE=0,ILAMBD=2,IOPAC=1,ISTART=1,ISUM=0,
ITMAX=40,ITRAN=0,NMU=5,
IWABND=0,IWATMS=0,IWATOM=0,IWCHAN=0,IWDAMP=0,IWEMAX=1,IWEQW=0,
IWEVEC=0,IWHEAD=0,IWHSE=0,IWLGMX=1,IWLINE=0,IWLTE=0,IWN=0,IWNIIT=0,
IWOPAC=0,IWRAD=0,IWRATE=0,IWSTRT=0,IWTAUQ=0,IWTEST=0,IWWMAT=0,
IWJFIX=0,IWARN=0,IOPACL=0,ISCAT=0,INCRAD=0,INGACC=0,ICRSW=0,
IOSMET=0,EOSMET=0.5,
IDL1=1,IDLNY=1,IDLCNT=1,IDLOPC=1
```

RH

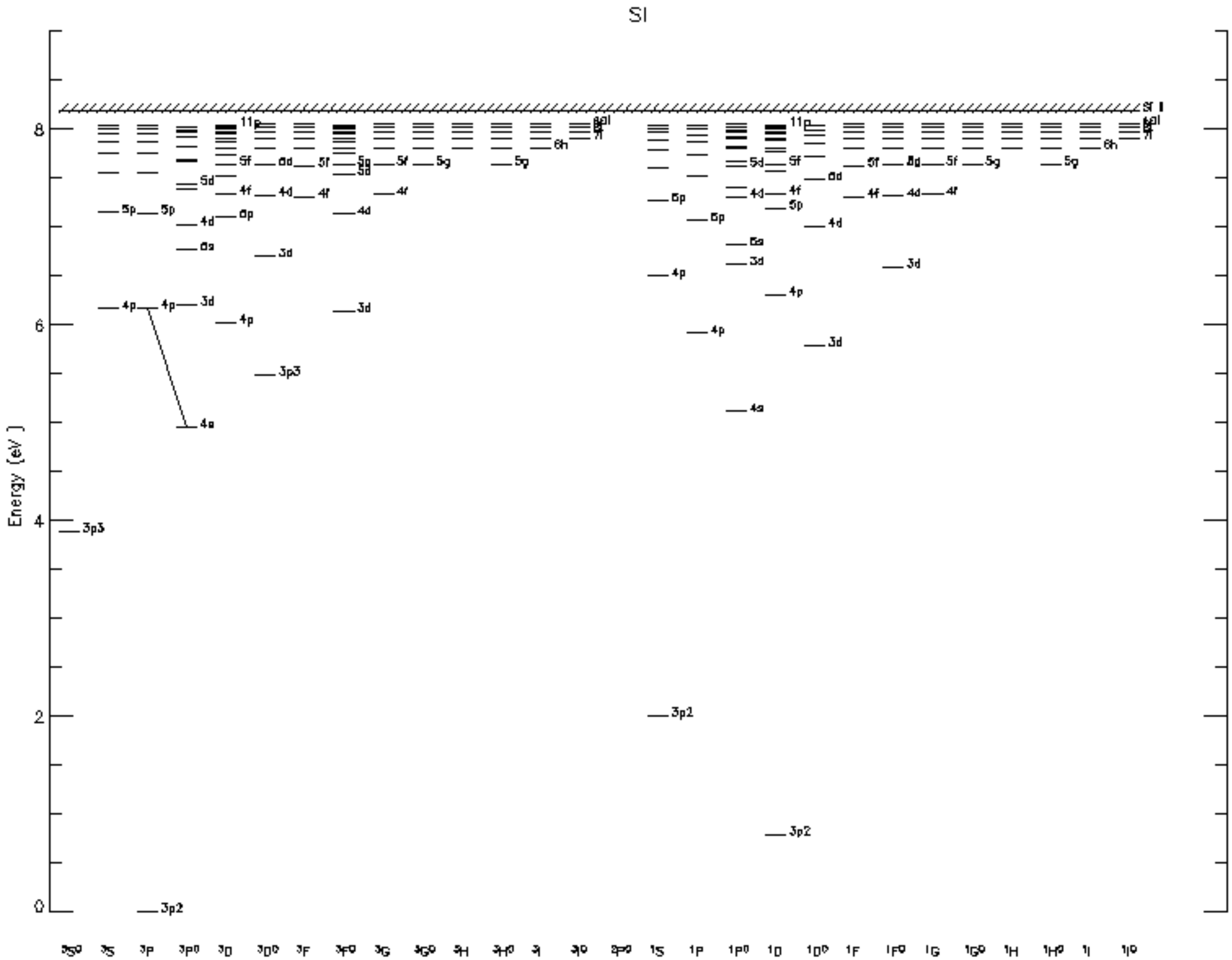
http://iris.lmsal.com/software.html

Uitenbroek, 2001, ApJ 557, 389 Pereira & Uitenbroek, 2015, A&A 574, 3

- 1D, 2D, 3D Cartesian, 1D spherical, 1.5D
- Statistical equilibrium
- given atmosphere {T, Ne, Vz, Vmic}([x,y,]z)
- many elements at the same time, full blends
- PRD, angle dependent
- Full Stokes (I,Q,U,V)
- Hydrostatic equilibrium can be solved for

R C S

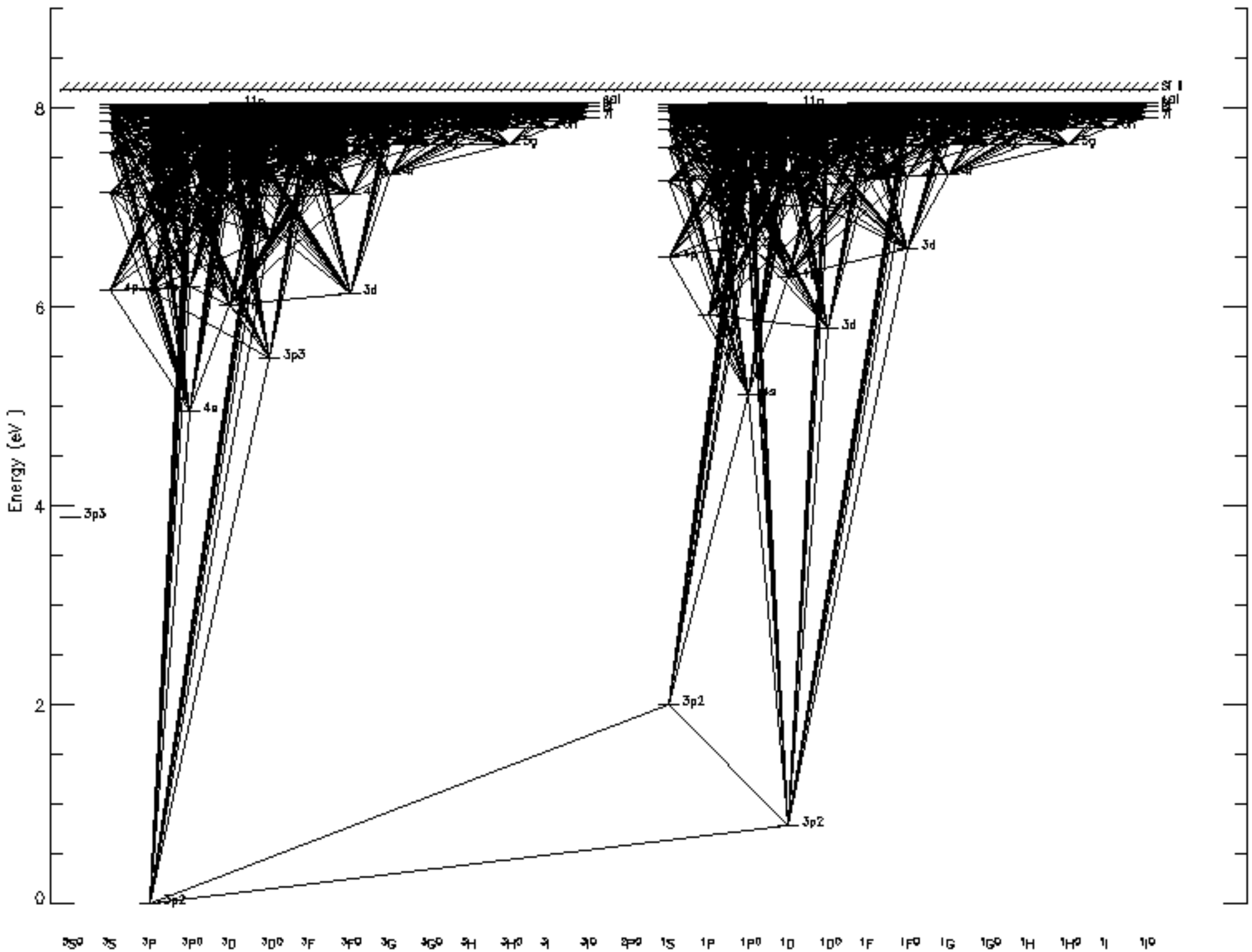
non-LTE modelling of Si I



Bard, Carlsson, 2008, ApJ 682, 1376

R C S

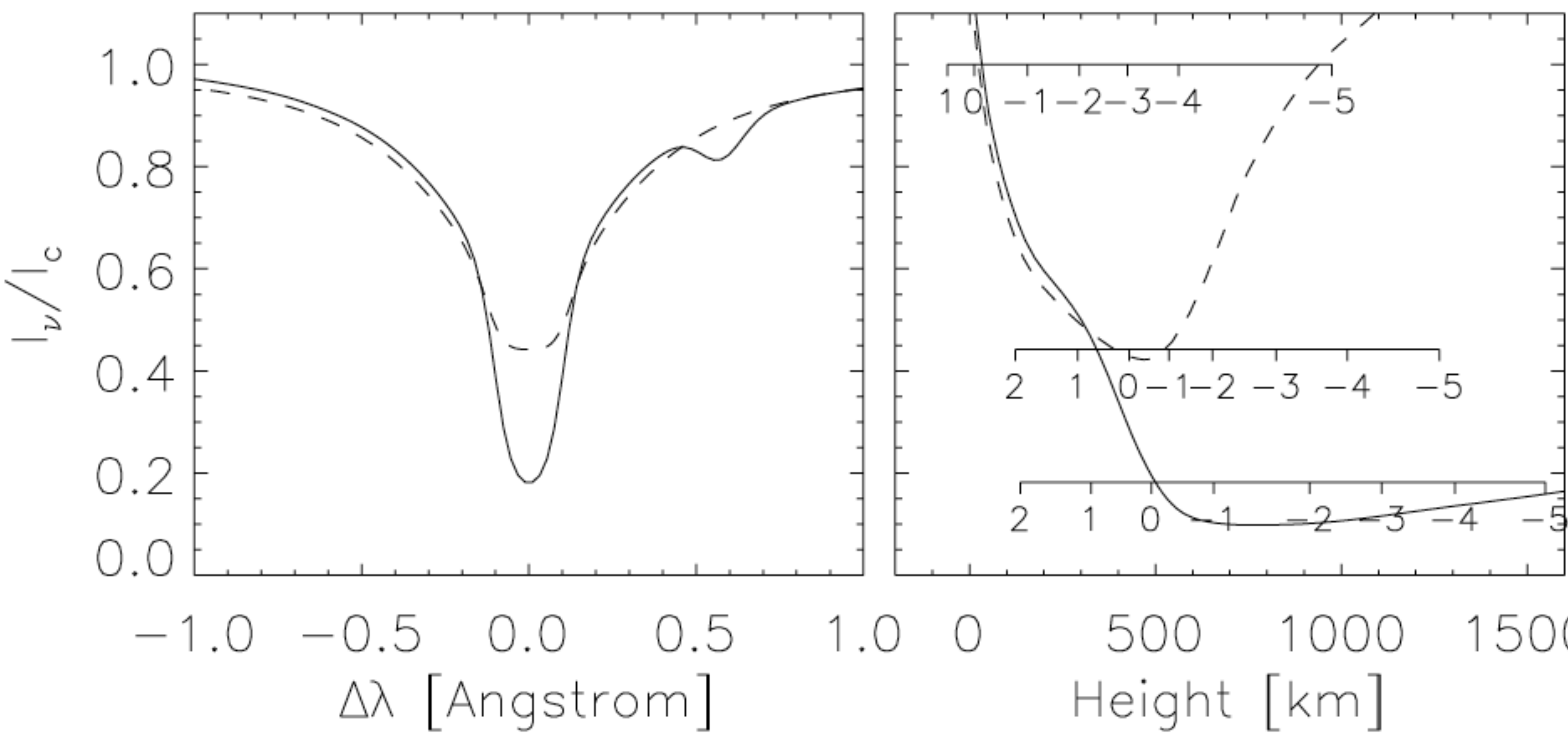
non-LTE modelling of Si I



We need a lot of atomic data!

R C S

Si 10827 Å line in FALC



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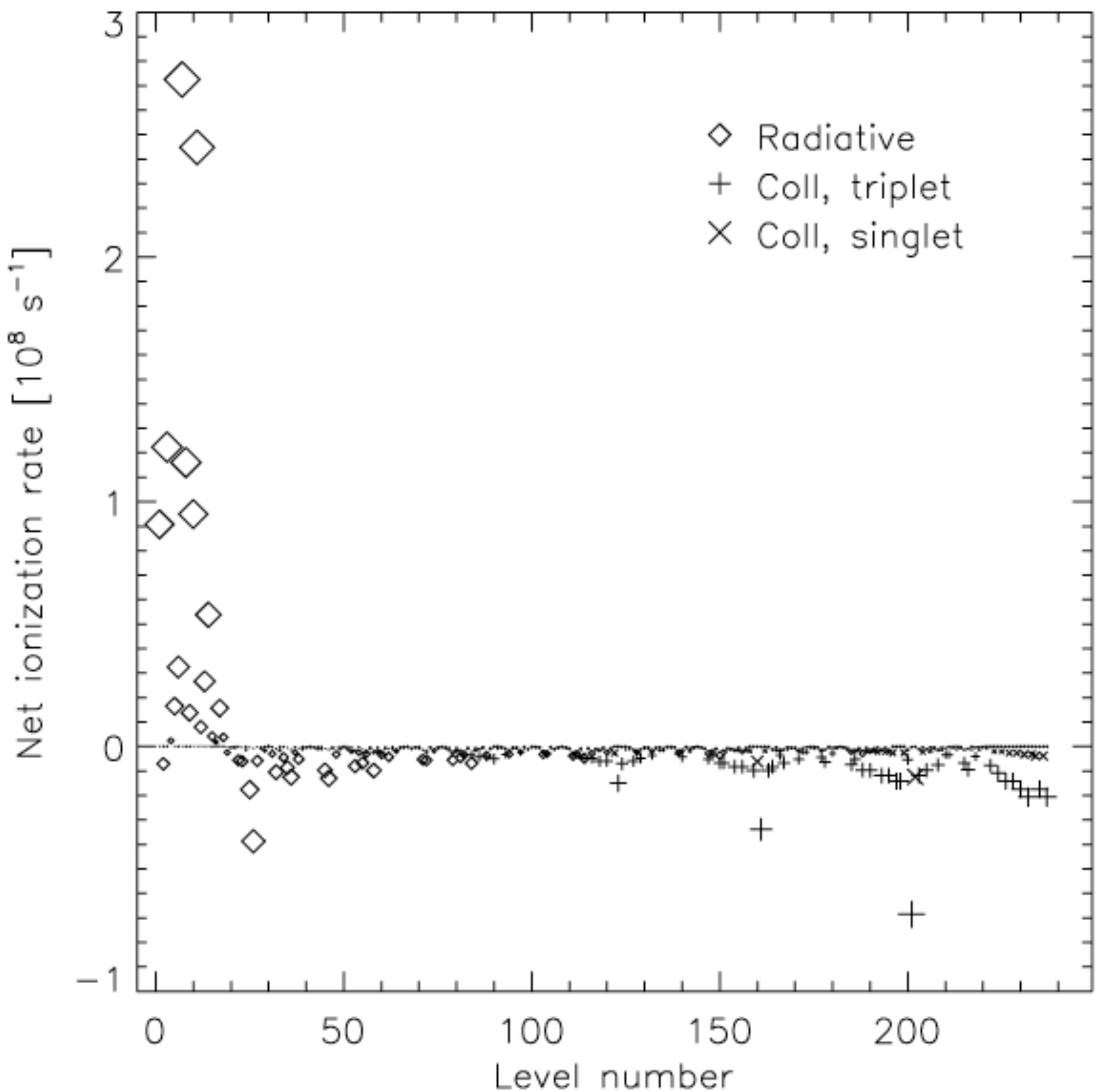
Ionization equilibrium



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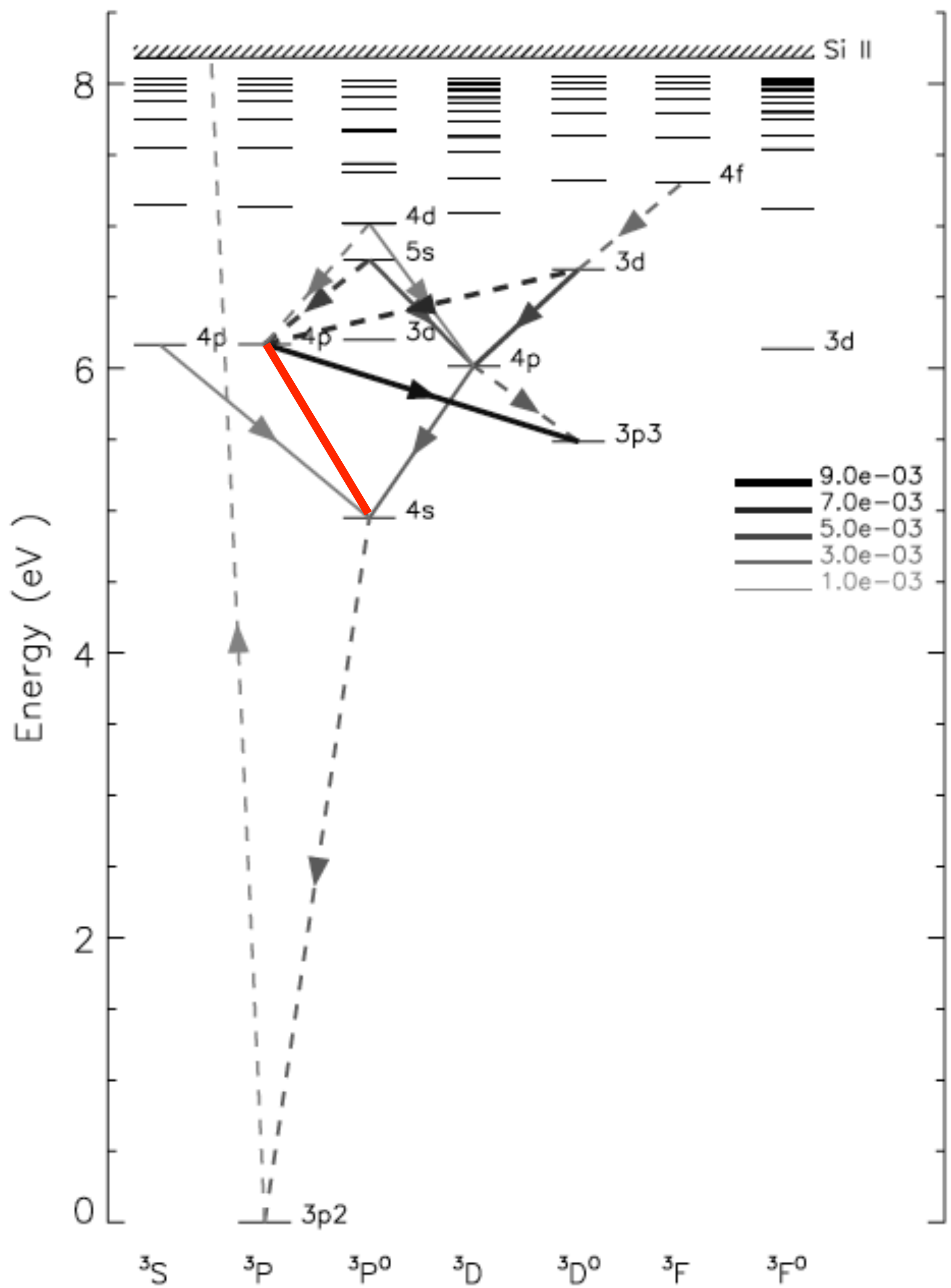
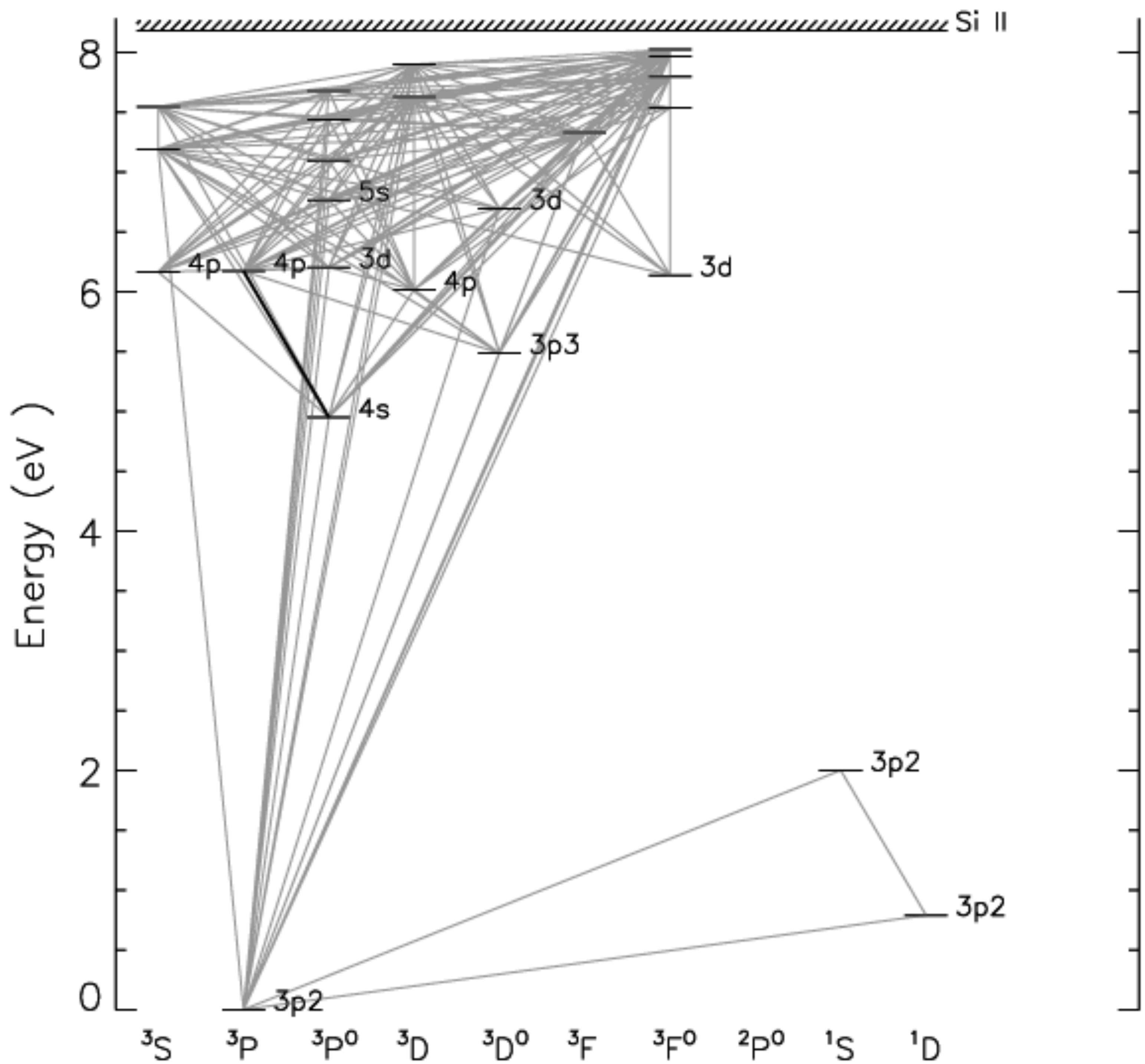
Influence of different rates



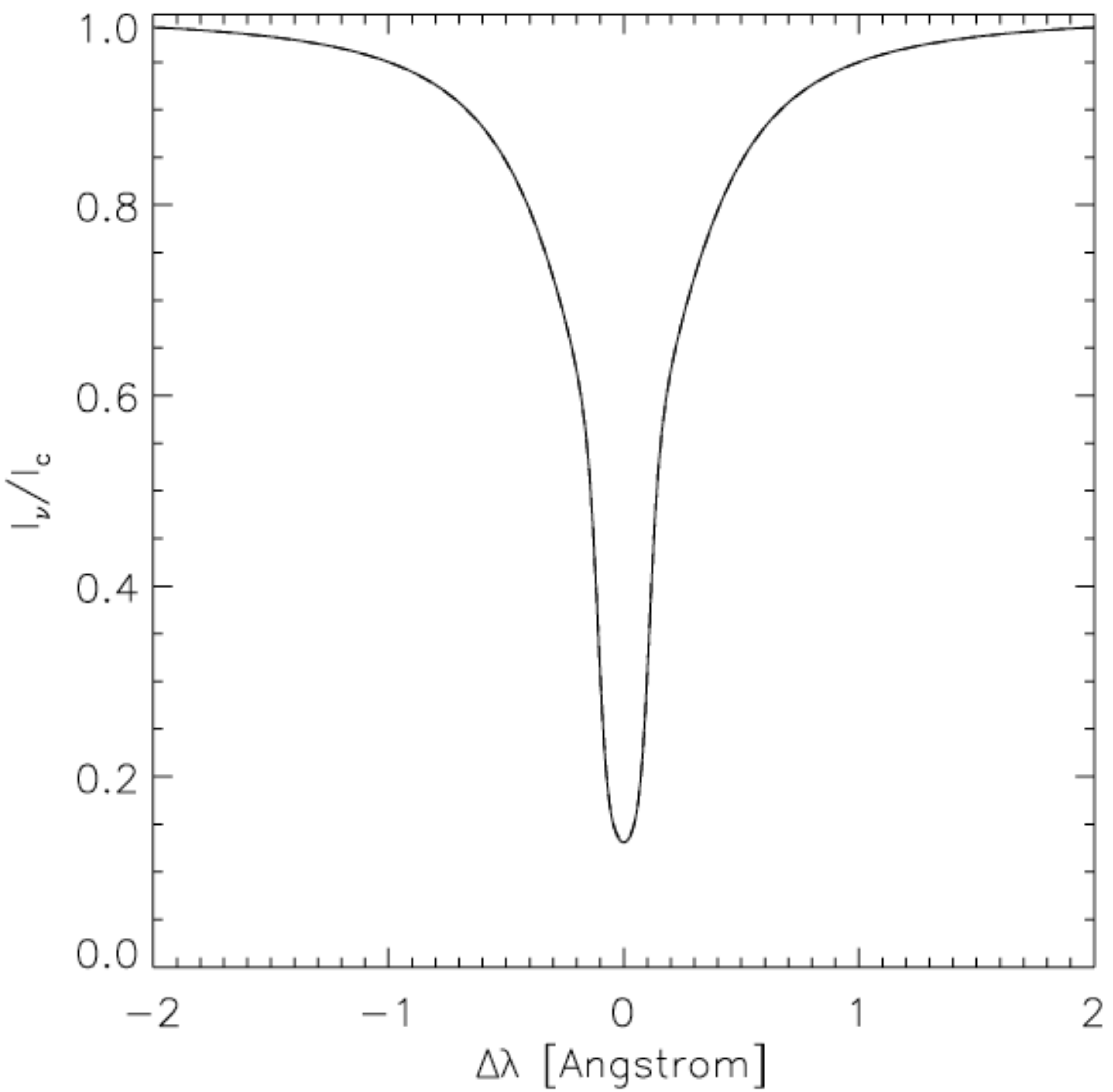
Simplified model atom

23 levels, 149 lines, 22 continua



R C S

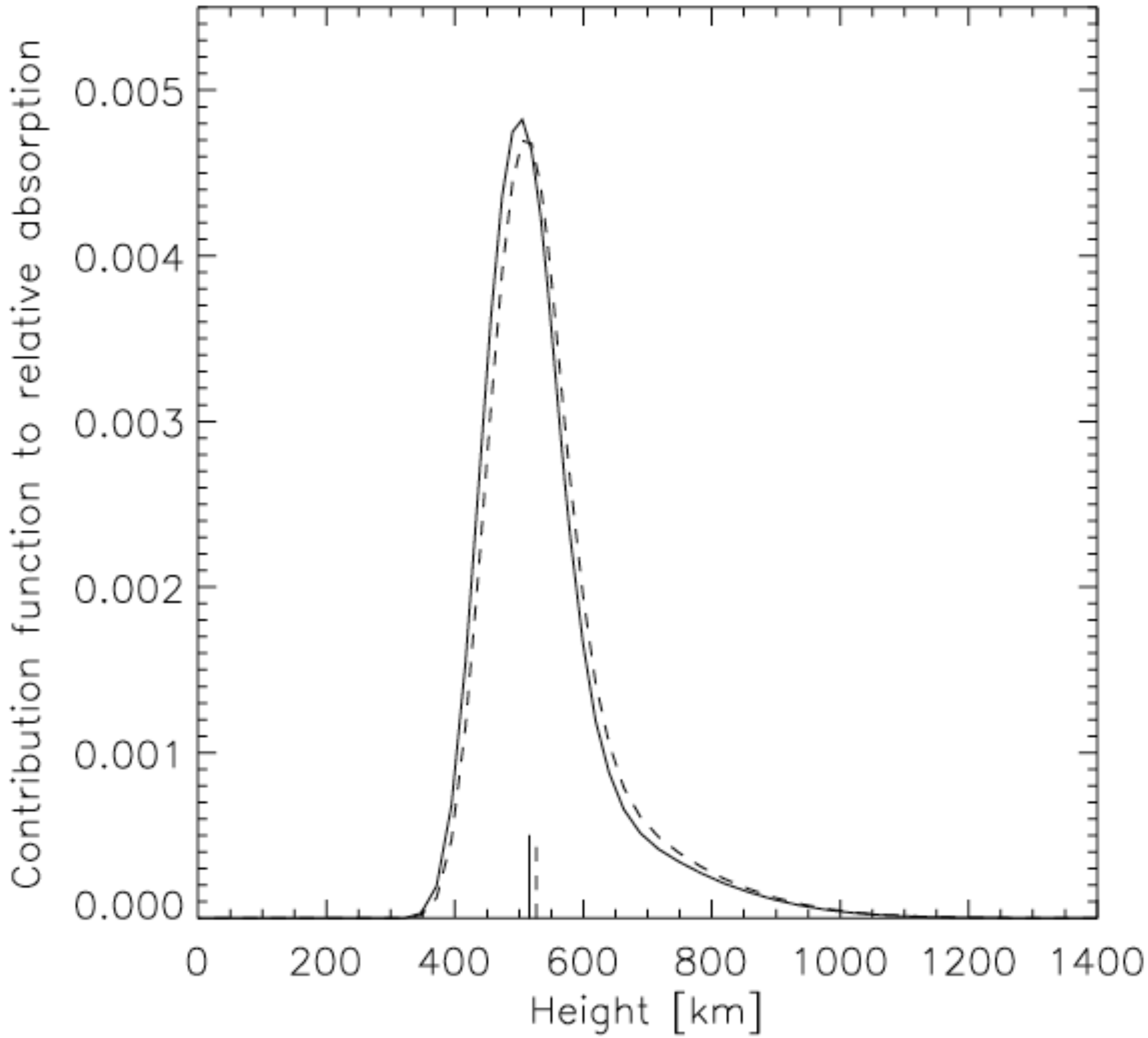
Intensity, FALC



Solid: large model atom
Dashed: simplified model atom

R C S

Contribution function to relative absorption

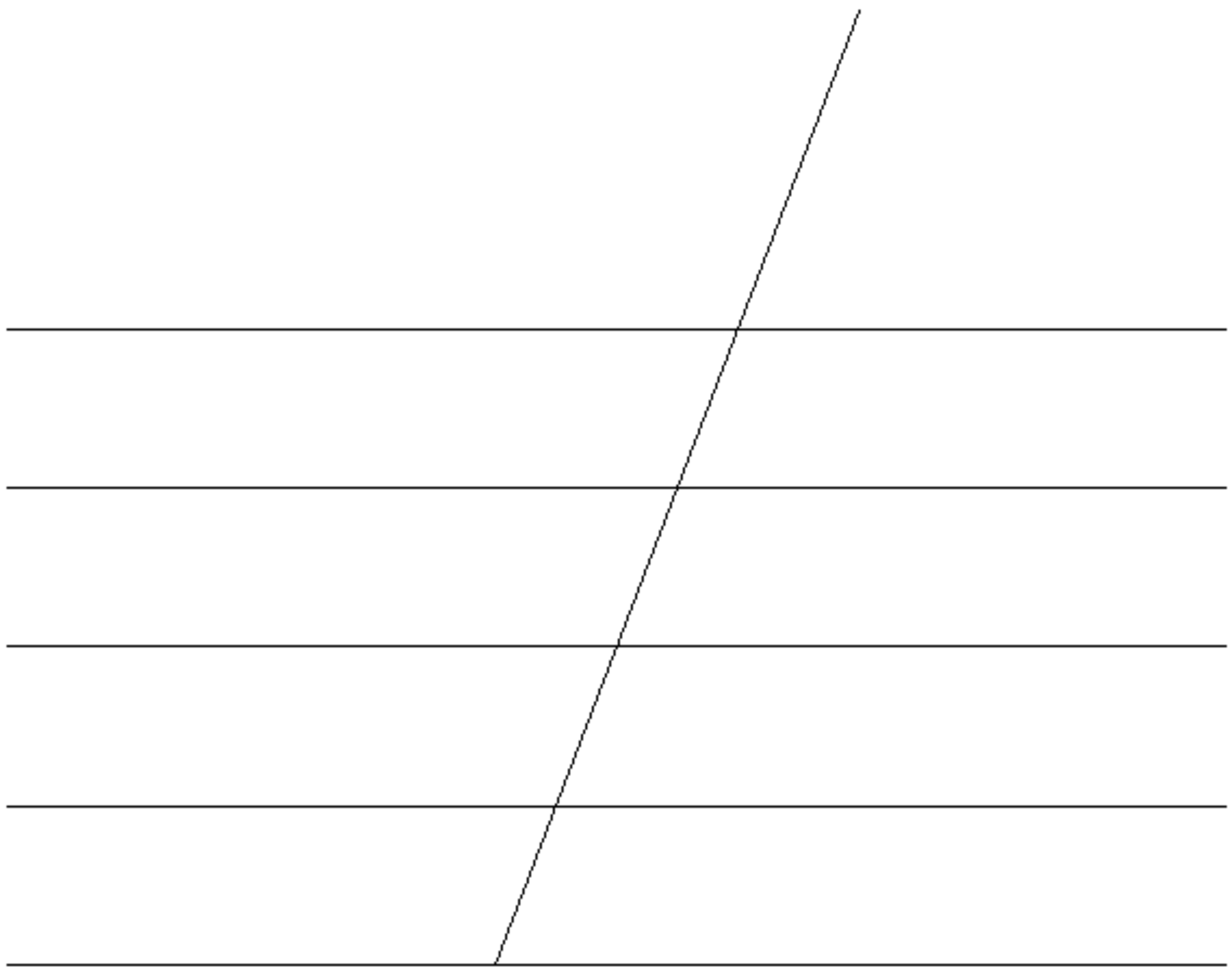


Solid: large model atom
Dashed: simplified model atom

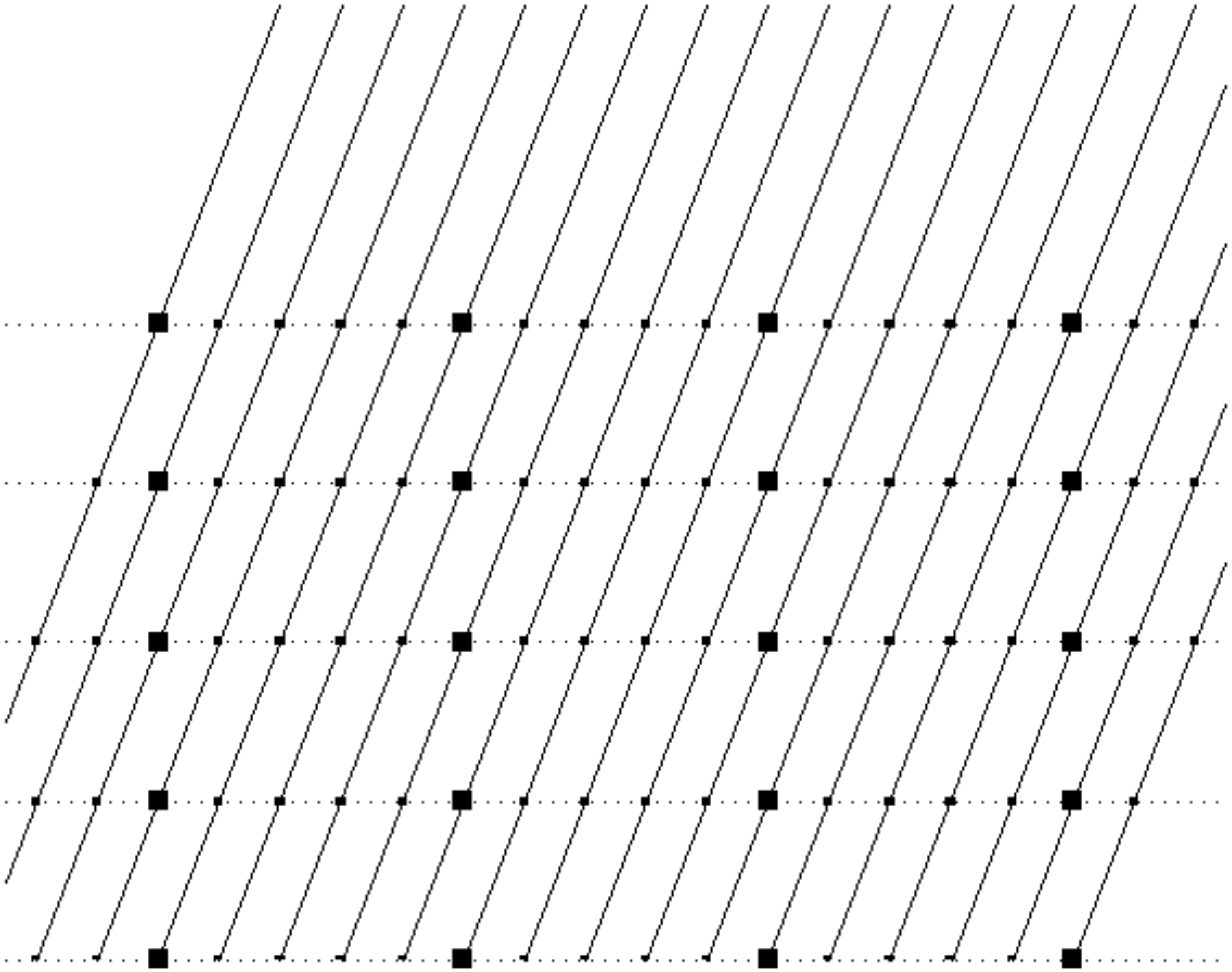
R C S

2D-3D

In 1D all rays pass through all grid “points” (planes).



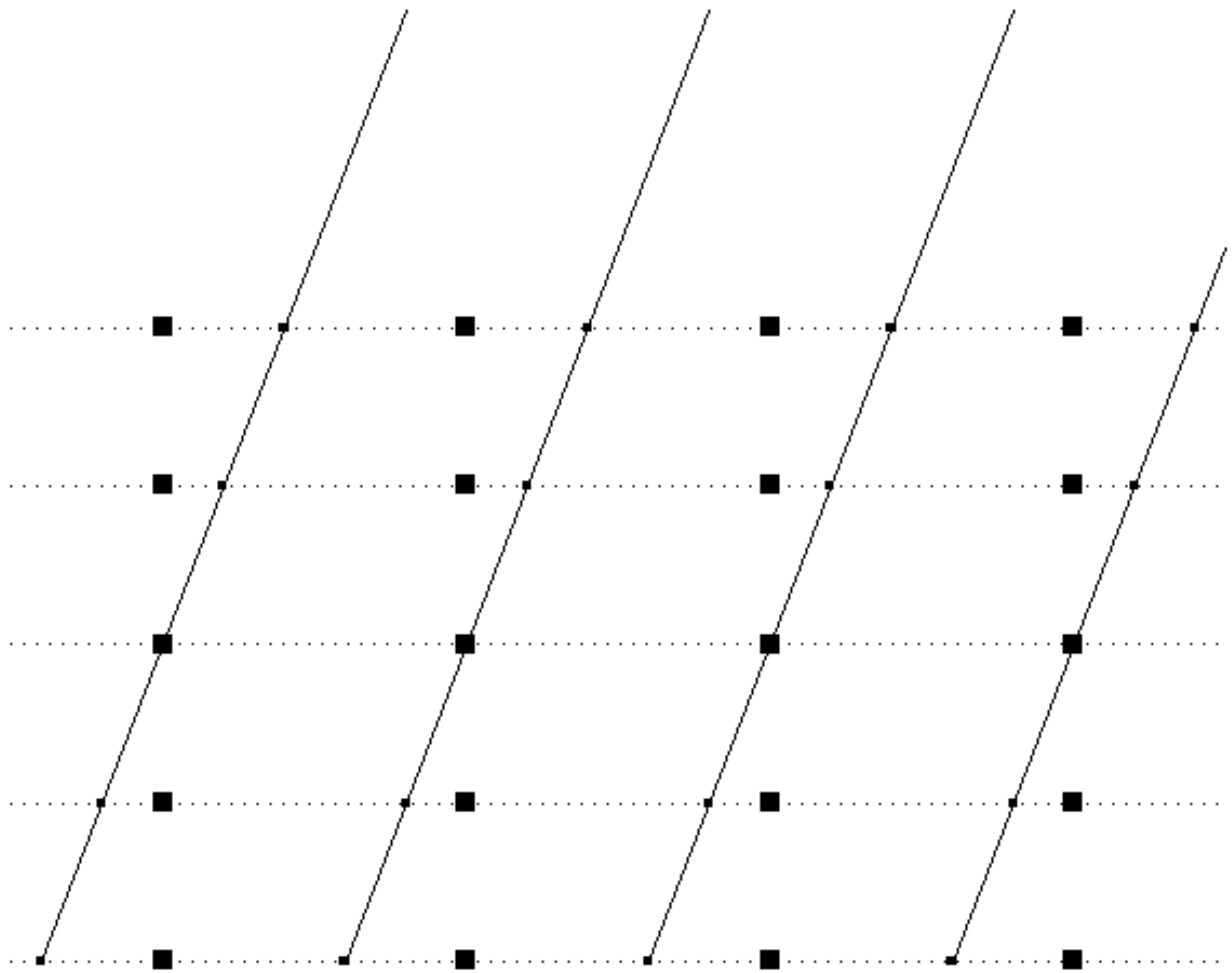
Long characteristics through all grid-points



Many rays: slow

R C S

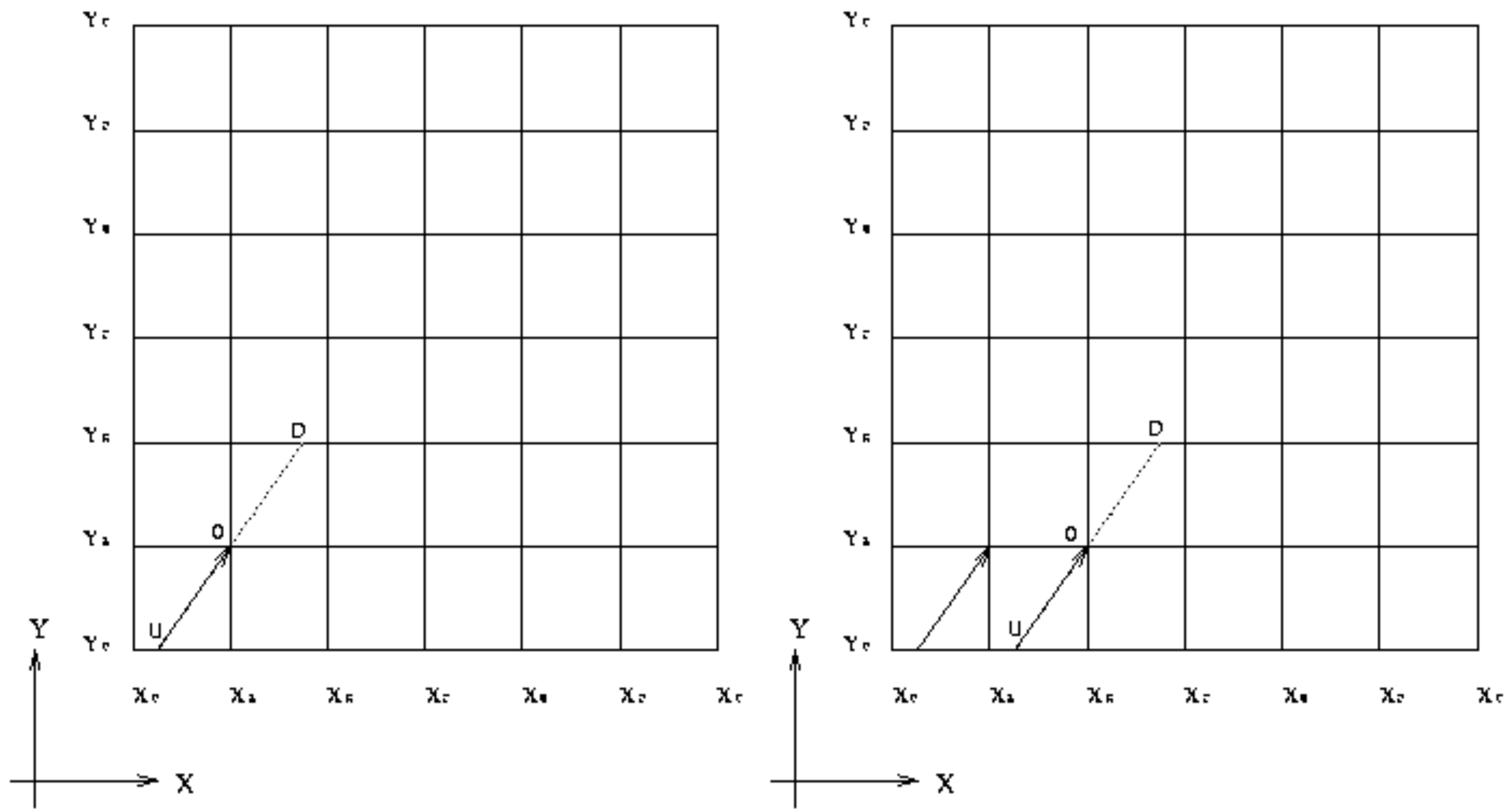
Long characteristics through one plane



Fast but may miss localized sources

R C S

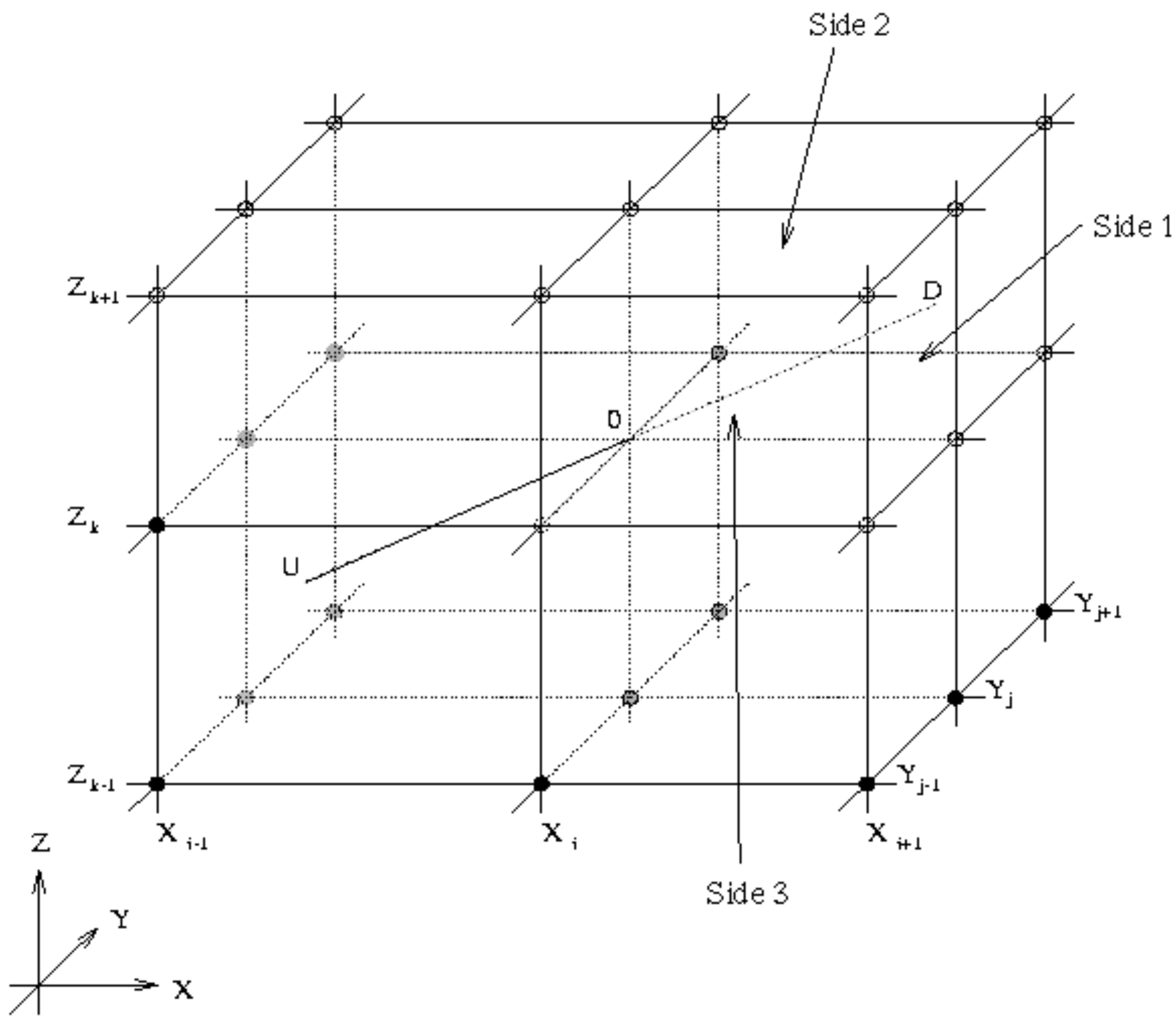
Short characteristics



Approximate S through 3 points (U, O, D), integrate analytically

Diffusive

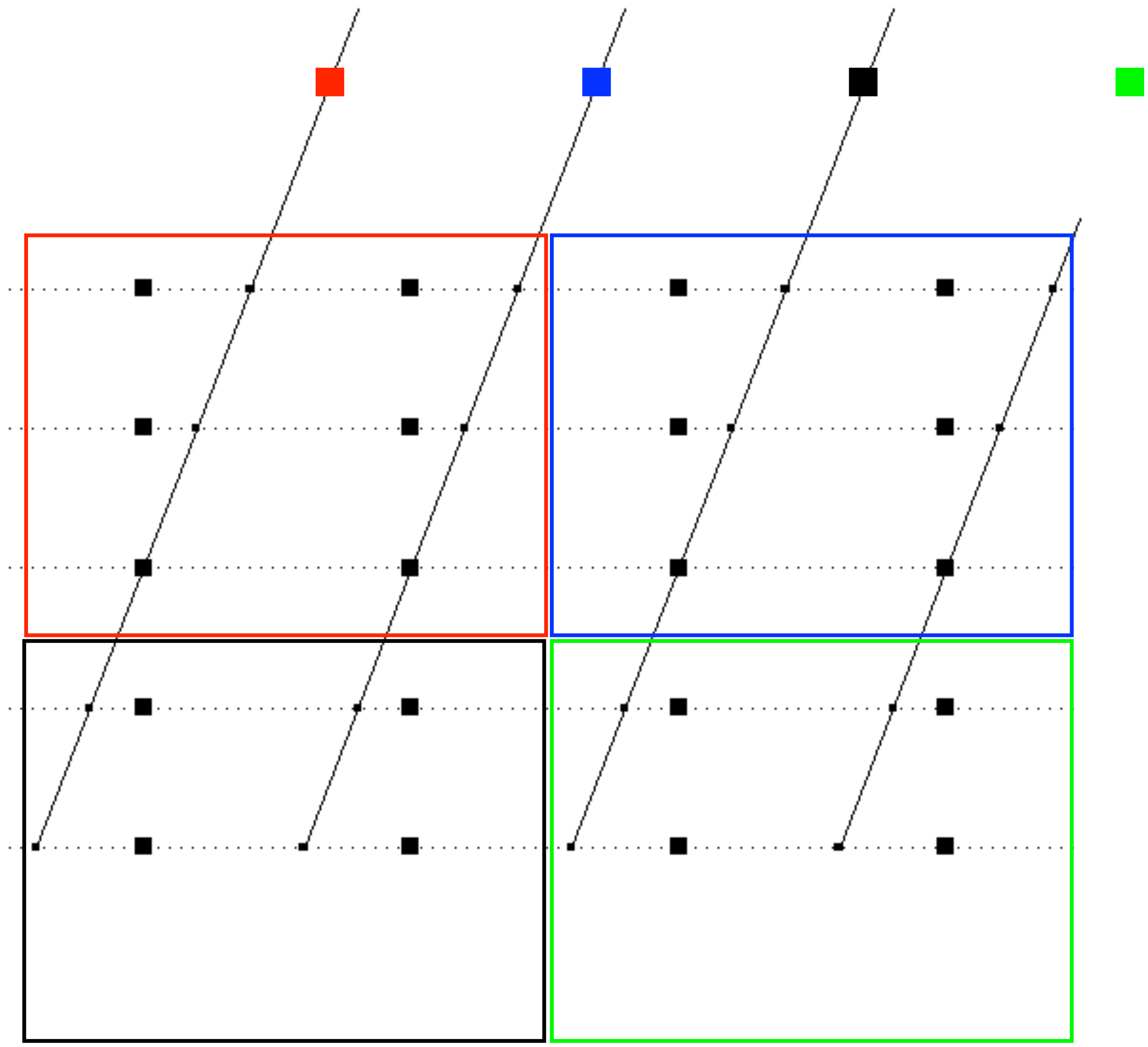
Short characteristics in 3D



R C S

Parallelization strategies

over rays: SMP OK

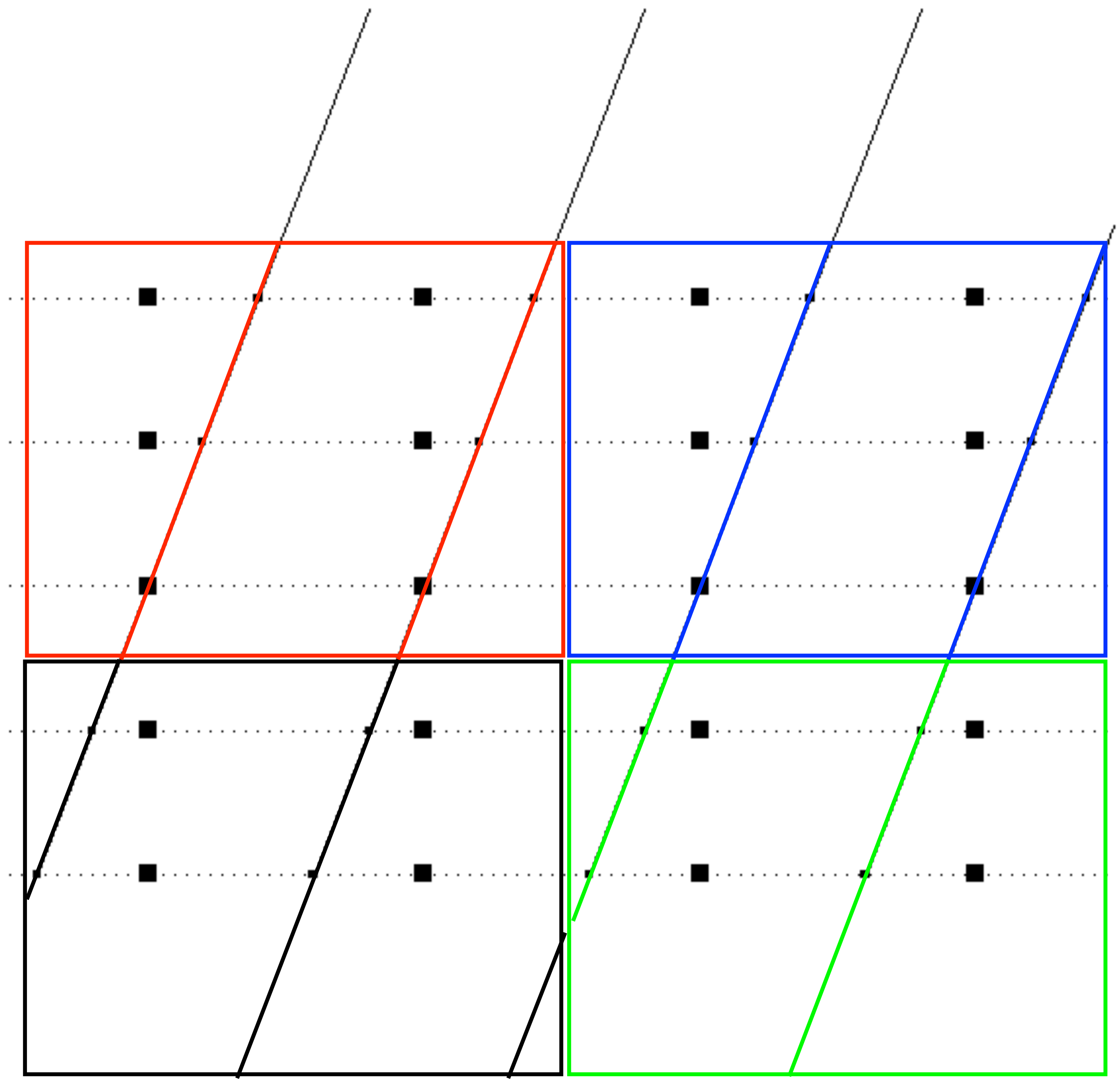


MPI: massive communication

R C S

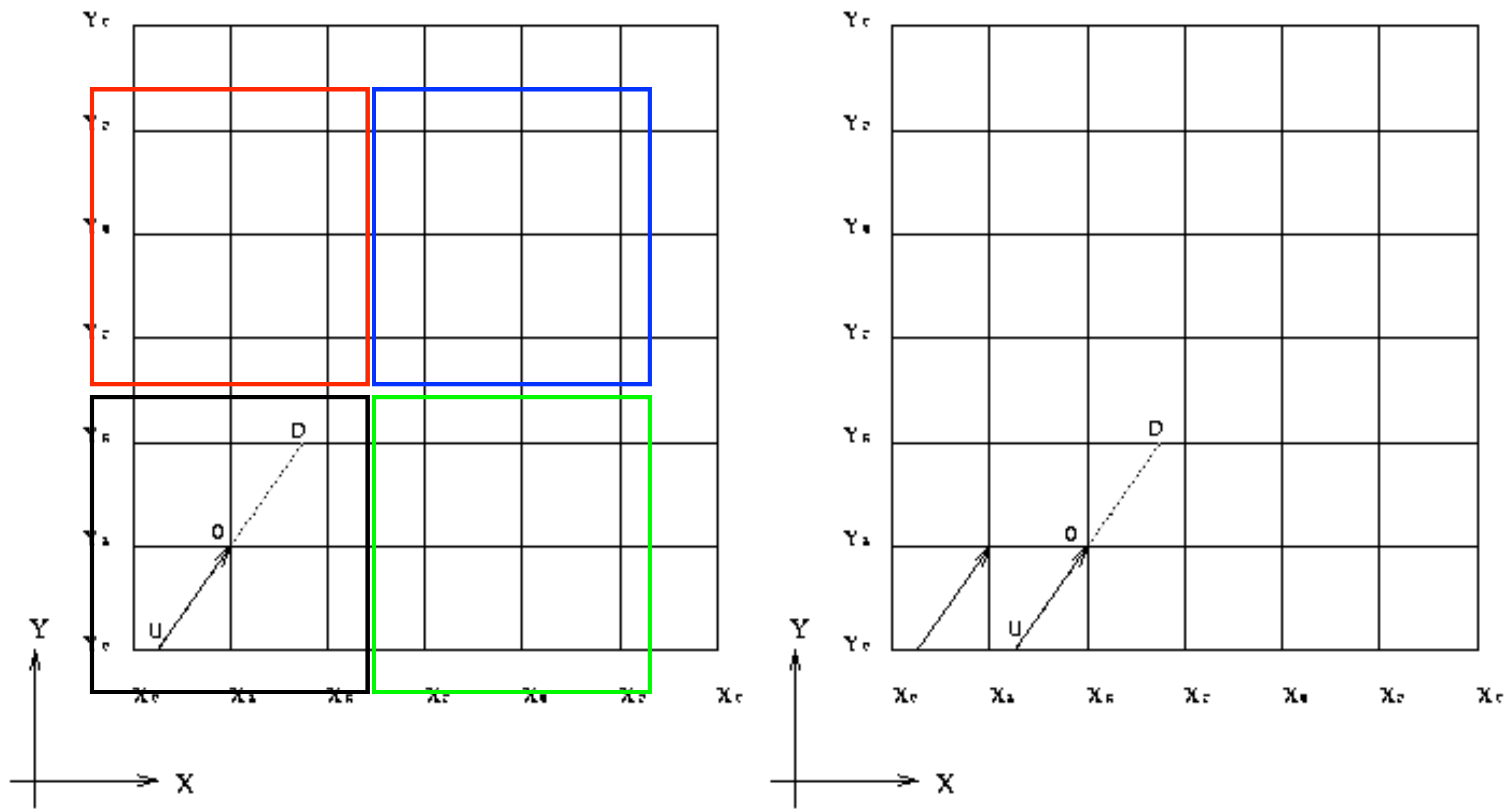
Parallelization strategies

Local rays



R C S MPI: simple communication, complicated admin

Short characteristics

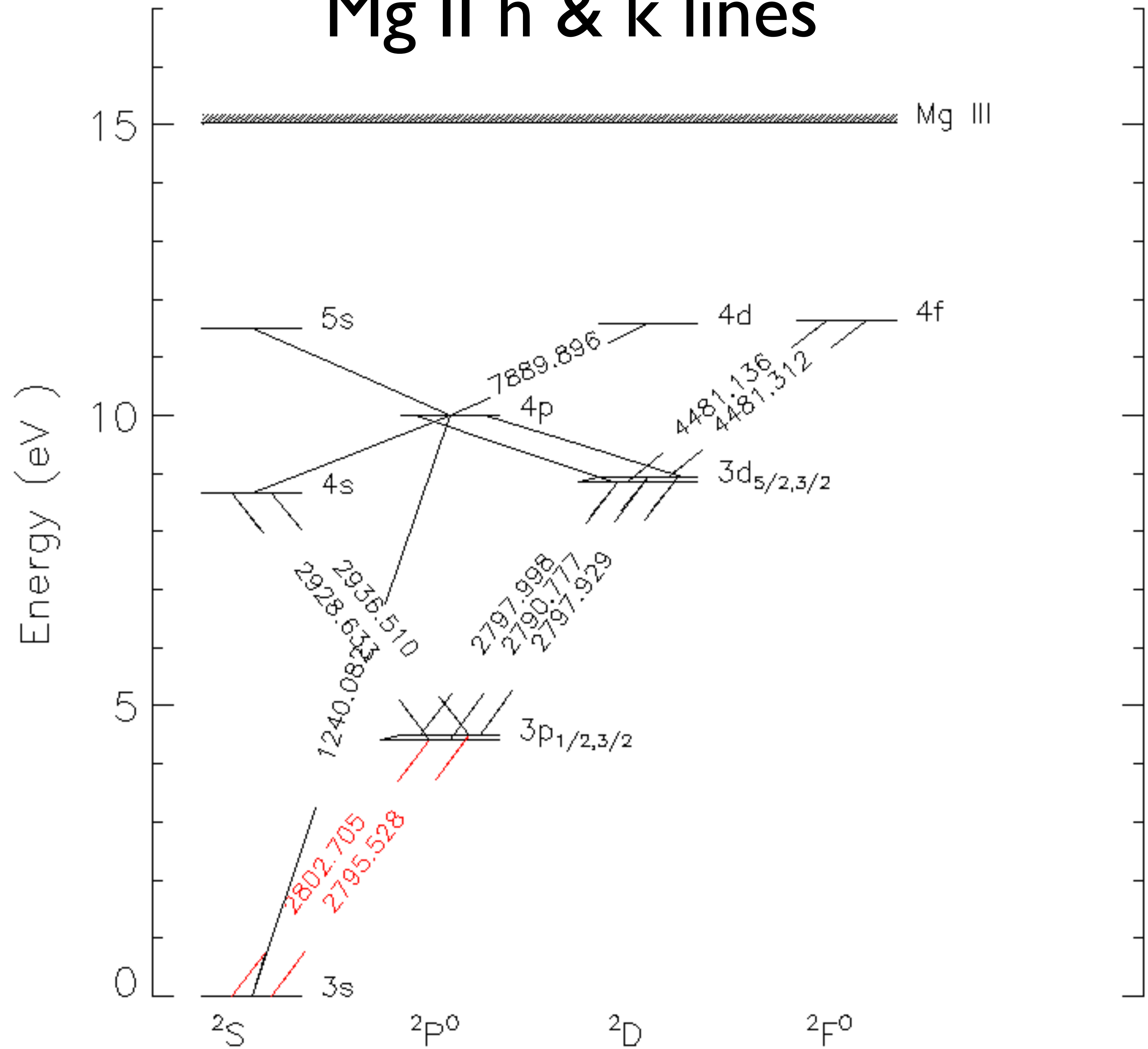


Order: passive processors
multiple sweeps

3D radiative transfer

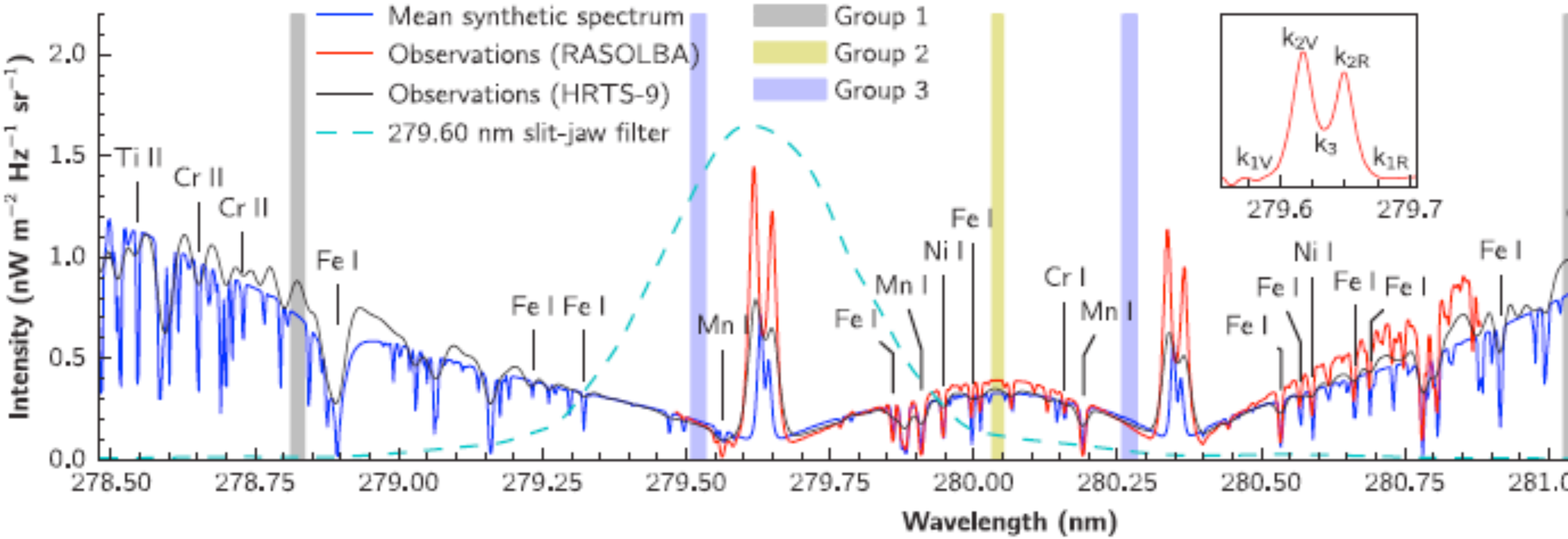
- IRIS (Ibgui, Hubeny, Lanz, Stehlé)
- Phoenix (Hauschildt, Baron)
- RH (Uitenbroek)
- MULTI3D (Botnen, Leenaarts, Carlsson)
- ? (Leenaarts)

Mg II h & k lines



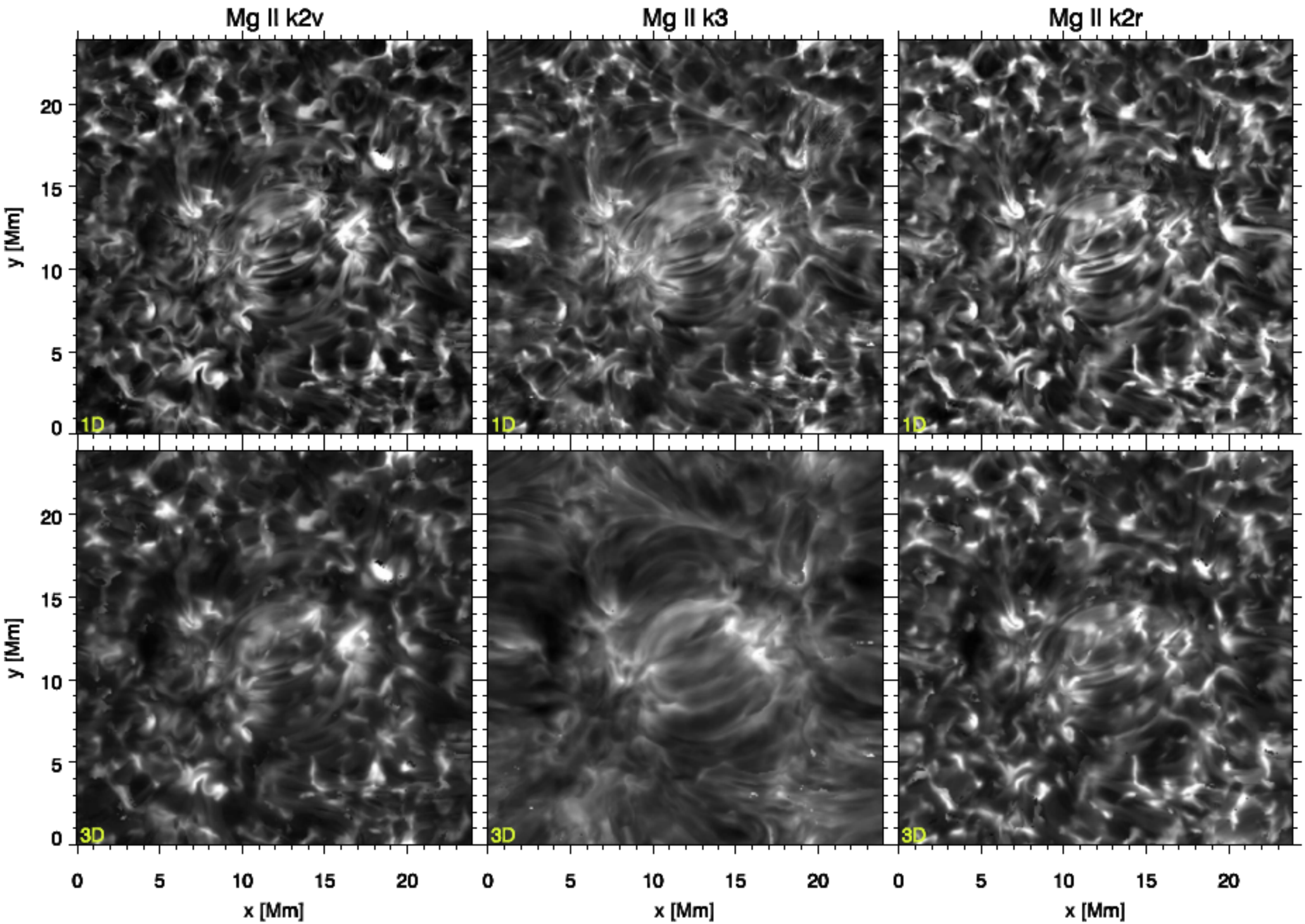
R C S

Mg II h & k lines



R C S

Pereira, Leenaarts, De Pontieu, Carlsson, Uitenbroek, 2013, ApJ 778, 143

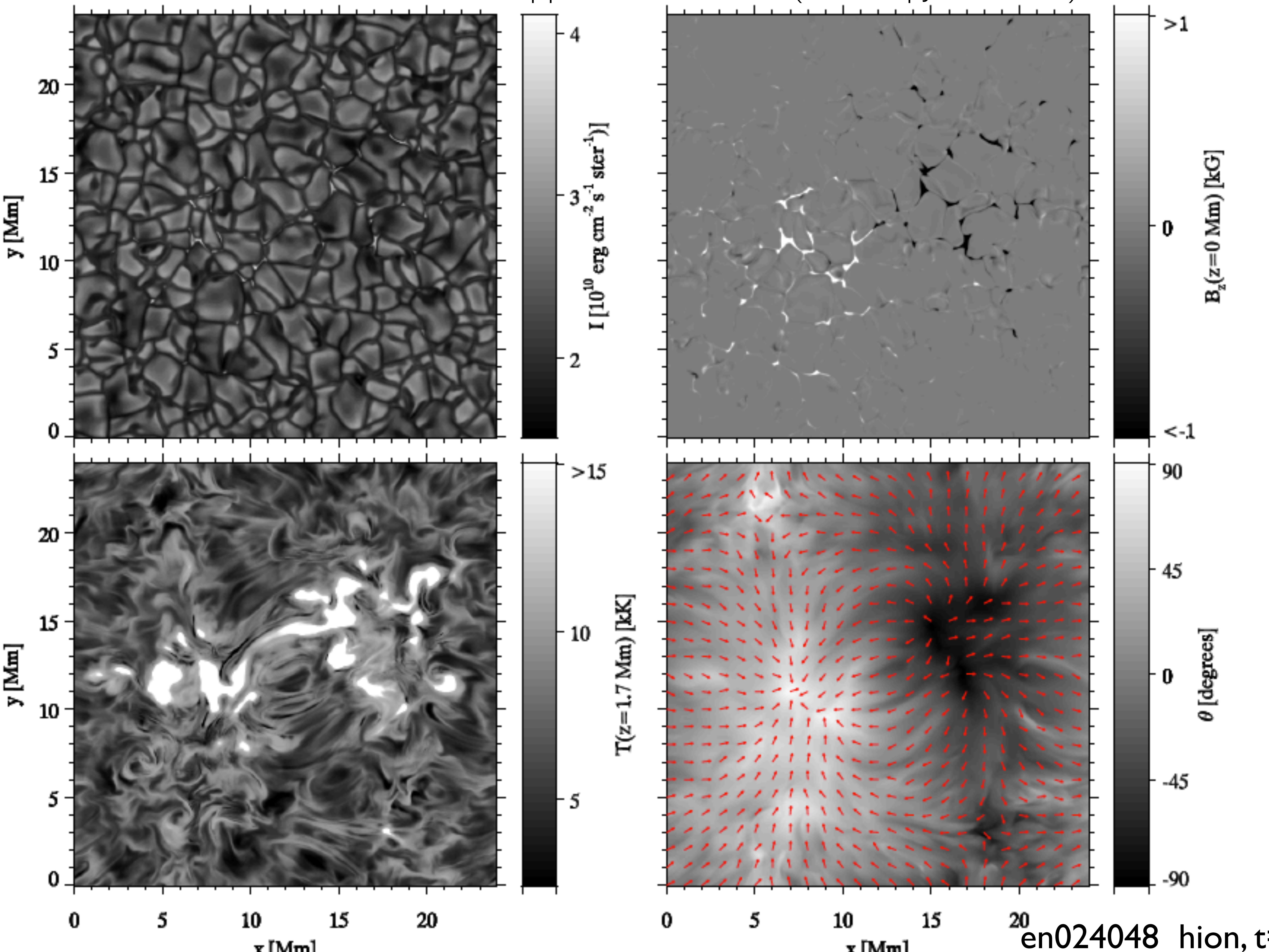


R C S

Leenaarts, Pereira, Carlsson, Uitenbroek, De Pontieu, 2013, ApJ 772,89

H-α

Leenaarts, Carlsson, Rouppe van der Voort (2012, ApJ 749,L136)



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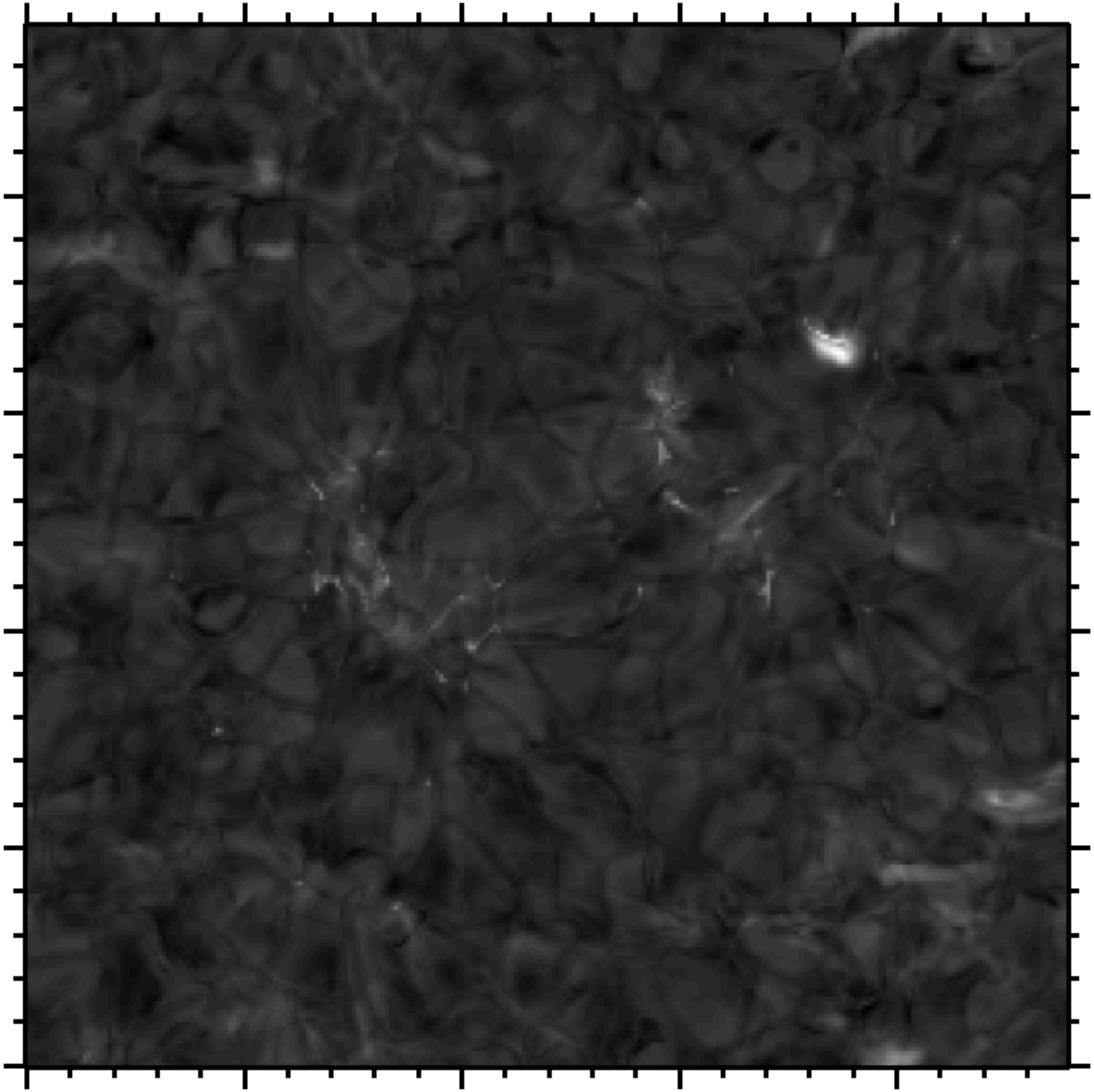
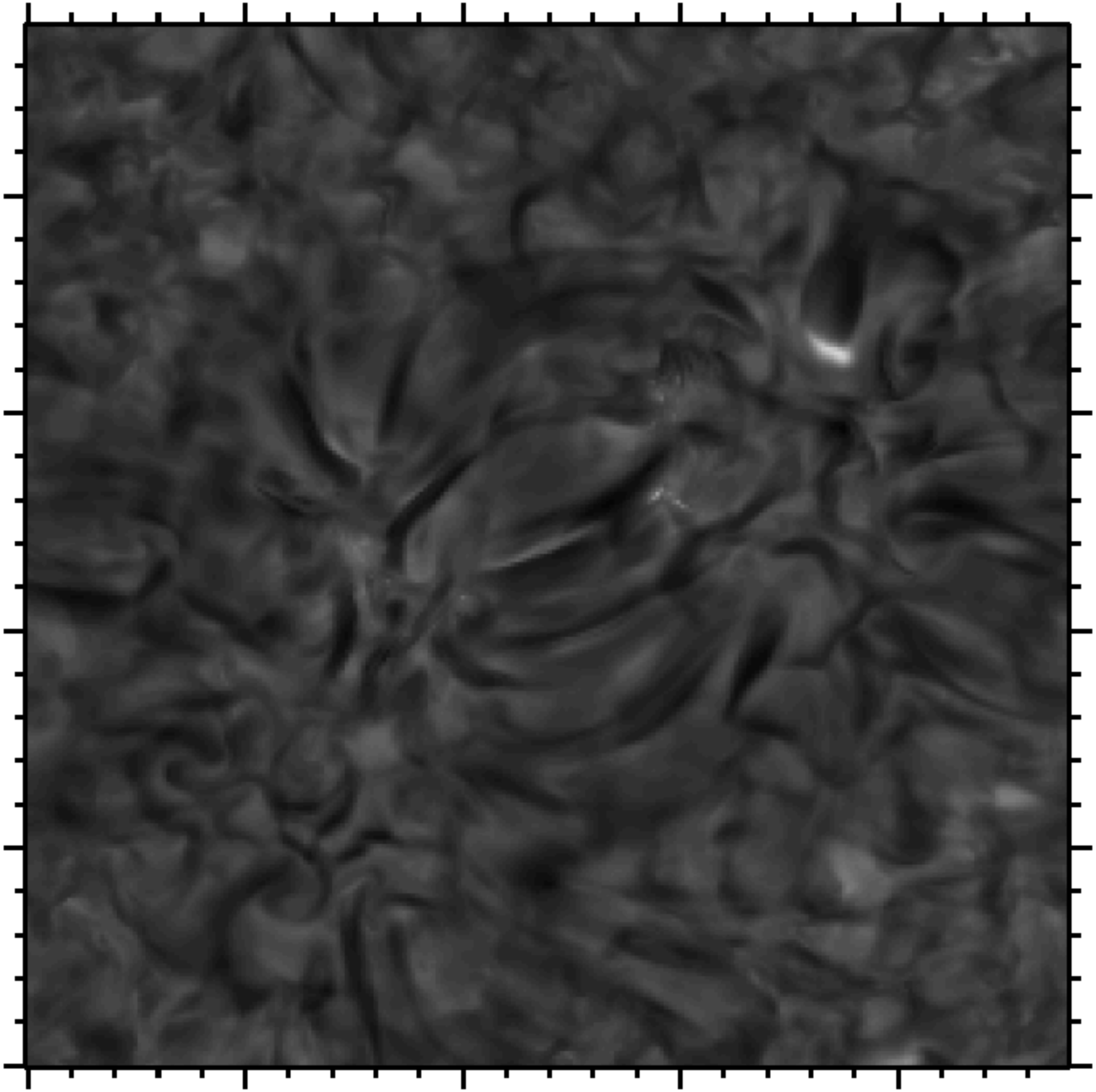
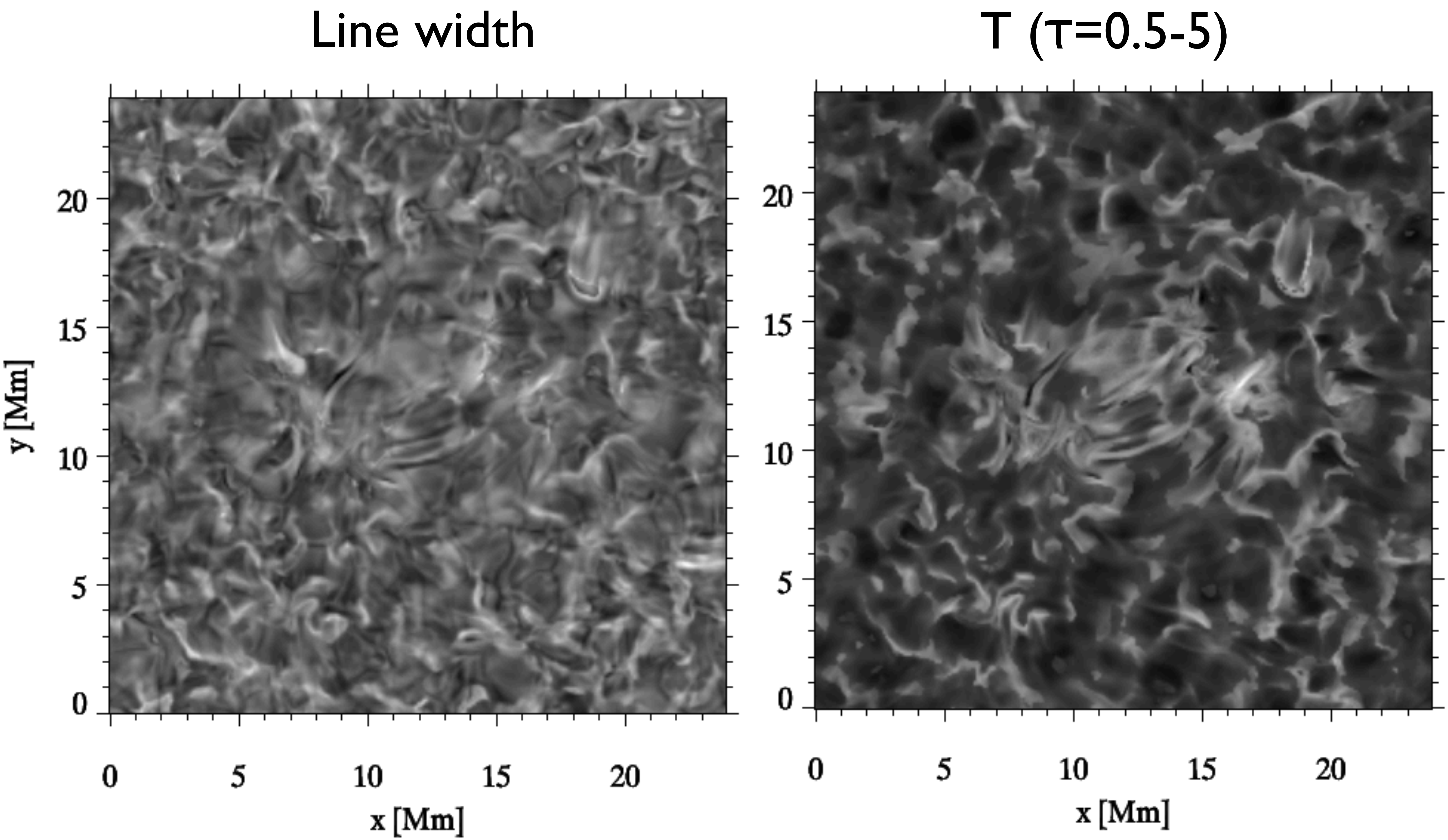
1D



3D



R C S



R C S