atlant 1.0: User's manual

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1 List of files

1.1 Initial files

1. atlant_1_0.cpp - original cpp code
2. cosm_p.in - file of cosmological parameters
3. fine_effects.in - file of switches of "fine" effects
4. fudge_factors.in - file of fudge factors
5. fund.in - file of fundamental constants
6. redshifts.in - integration boundaries, integration step and other parameters
7. lnx_atlant_1_0.x - atlant executable file for Linux
8. bsd_atlant_1_0.x - atlant executable file for BSD Unix
9. win_atlant_1_0.exe - atlant executable file for Windows
10. cygwin1.dll - dynamic library ensuring correct work of win_atlant_1_0.exe
11. manual.pdf - user's guide for **atlant**

1.2 Resulting files

1. el.dat - file of free electron fraction
2. HeI.dat - file of HeI fraction
3. HeII.dat - file of HeII fraction
4. HeIII.dat - file of HeIII fraction
5. Hyd_Rad_Overheat.dat - technical file to store relative overheating
6. HydI.dat - file of HI fraction
7. HydII.dat - file of HII fraction

2 Comments for initial files

1. Note that there is no necessity to compile file of original code "atlant_1_0.cpp" if you do not make an essential changes of physical model (e.g. adding new "fine" effect). For user's convenience we already have created executable files for most used operating systems.
2. Executable files do not show any messages if their work is successful. Their execution leads to appearance of resulting files in working directory.
3. All executable files are compiled from atlant_1_0.cpp by g++ (under BSD we have used g++ (GCC) 3.2.1 [FreeBSD] 20021119 (release)) with command line "g++ -O3 atlant_1_0.cpp". Of course other compilers can be used but additional header-files may be demanded.

If compiler says about the problems with the scopes of C-functions (e.g. with "cout") you can replace header-files

```
# include <iostream.h>
# include <fstream.h>
# include <math.h>
# include <stdio.h>
```

by the following (remark by M.S. Burgin):

```
————————————————————————
# include <iostream>
# include <fstream>
# include <cmath>
using namespace std;
————————————————————————
```

4. Corresponding access permissions for files should be provided (if necessary), e.g.:
use "chmod 744 *" in directory "atlant_1_0" under Unix;
disable check box 'read only' for used files under Windows;
5. Please do not change general structure of "*.in" files (e.g. do not shift symbol "="). Change only the values after symbol "=".
6. Current version of code allows us to take into account one of the "fine" effects - radiative feedbacks for resonant transitions in hydrogen atoms. So current file "fine_effects.in" contains the only parameter: number of levels for which feedbacks will be taken into account. Note that value "1" corresponds to common three-level model of recombination without any feedbacks for resonant transitions.
7. File "fudge_factors.in" contains value of fudge factor F_H and the parameters of the perturbation fudge function δ_X affecting free electron fraction by means of the following relation:

$$x_e^{res} = x_e^{calc} \left(1 + \delta_X\right) \tag{1}$$

where x_e^{res} is the free electron fraction (normalized by total number of hydrogen atoms and ions) being the final result of work of recombination code (i.e. it is value shown in the resulting file), x_e^{calc} is the solution of ODE's system describing ionization fractions and free electron fraction.

In the current version of code the Lorentzian-like function has been chosen to describe uncertain (until now) deviations of free electron fraction from well known ODE's solution:

$$\delta_X = \frac{A_p}{1 + \left[\left(z - z_p\right)/\Delta z_p\right]^2} \tag{2}$$

where A_p is the relative amplitude of perturbation of ionization fraction, z_p is the redshift of perturbation maximum, Δz_p is the half-width of perturbation function at half-altitude.
8. File "redshifts.in" determines the values of initial redshift of integration, final redshift of integration, relative step of integration in redshift-space $\Delta z/\left(1+z\right)$. For the integration of ODE's system the implicit method of second order of accuracy is applied.

This file also contains the criterion for convergence of discrepancy norm defined by:

$$||X|| = \sum_i \left| \frac{x_i - x_i^-}{x_i} \right| \tag{3}$$

where x_i is the fraction of i-th plasma component (i =HI, HII, HeI, HeII, HeIII), x_i^- is the fraction of i-th plasma component at the previous iteration. Since ODE's system is non-linear the **atlant** should resolve the system of non-linear algebraic equations at every step of integration. **Atlant** does it by means of iteration method, and the iteration process is considered to be converged when the norm $||X||$ achieves the criterion indicated in file "redshifts.in".

The last parameter of file "redshifts.in" determines the number of points shown in resulting files. For example if the value of this parameter equals 5 then only every 5-th point of integration net will be indicated in resulting files.

3 Comments for resulting files

1. Resulting files for fractions of components contain two columns. First of them is the redshift value. Second column is the fraction of corresponding component. Note that in files HydI.dat, HydII.dat, HeI.dat, HeII.dat, HeIII.dat the fraction is the ratio of concentration of corresponding component to the total concentration of hydrogen and helium atoms and ions, i.e.:

$$x_i = \frac{N_i}{N_H + N_{He}} \tag{4}$$

This definition is originated from earlier unpublished versions of **atlant**.

In the second column of file el.dat the free electron fraction is shown. Note that this value is the ratio of free electron concentration to the total concentration of hydrogen atoms and ions, i.e.:

$$x_e = N_e/N_H \tag{5}$$

This definition is in accordance with the common practice (e.g. **recfast**).

2. File Hyd_Rad_Overheat.dat is the technical file which is used by **atlant** during its work. It contains the two columns. First of them is the redshift value. Second column is the natural logarithm of relative overheating of Lyα radiation in comparison with its equilibrium value.

3. After execution with the parameters from present archive the file "el.dat" should contain the following values:

Table 1: Contents of el.dat

7996.0005	1.1590235
7992.003	1.1590234
7988.0075	1.1590234
.....	.....
200.2045	0.00032621231
200.10392	0.00032614812
200.0034	0.00032608397

4 Difference from recfast

Comparison of results is made with the **recfast** of version 1.5 (http://www.astro.ubc.ca/people/scott/recfast.for).

The main physically motivated difference of results by **atlant** and **recfast** appears in the period $z = 300 - 1000$. It arises due to different structure of ionization items of hydrogen kinetic equation (Peebles 1968, Zeldovich et al 1968, Seager et al. 1999, Wong et

al. 2008) in **atlant** and **recfast**: in **recfast** the ionization coefficient β_{HI} and Boltzmann exponential term $\exp(-h\nu_\alpha/[k_BT])$ are calculated at temperature of matter while in **atlant** at radiation temperature. The most part of this difference is due to distinction of ionization coefficients included in the denominator of inhibition coefficient C_{HI}. The maximum of $\Delta x_e/x_e$ in mentioned range of redshifts is about 0.27% at $z \simeq 770$ (see Fig. 1). This is little but maybe important difference in the context of future analysis of Planck data.

5 Concluding remarks

The detailed description of physical model used in **atlant** will be presented soon in paper by Kholupenko, Ivanchik, Balashev, and Varshalovich (in preparation).

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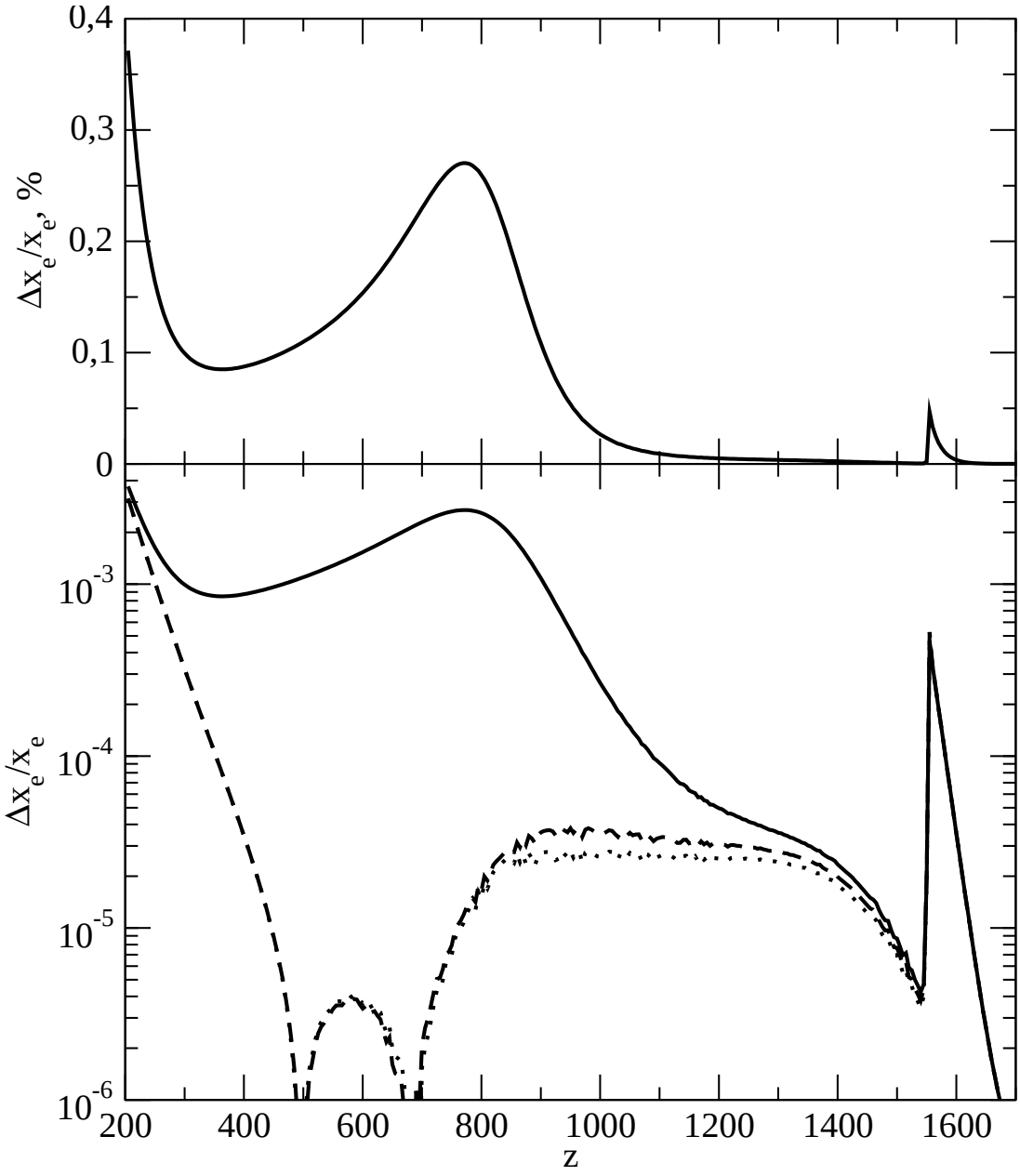

Figure 1: Top panel: relative difference $\Delta x_e/x_e$ between free electron fractions calculated by **atlant** and **recfast** for the period of hydrogen recombination. Bottom panel: (i) solid curve corresponds to the relative difference $\Delta x_e/x_e$ between free electron fractions calculated by **atlant** and **recfast** [i.e. the same as in the top panel but in logarithmic scale], (ii) dashed curve corresponds to the relative difference $\Delta x_e/x_e$ between free electron fractions calculated by **atlant** and **recfast** with corrected ionization rate [i.e. ionization coefficient $\beta_{HI}(T)$ and exponential term $\exp(-h\nu_\alpha/[k_BT])$ in hydrogen kinetic equation of **recfast** are calculated at the temperature of radiation T], (iii) dotted curve corresponds to the relative difference $\Delta x_e/x_e$ between free electron fractions calculated by **atlant** with modified ionization rate [i.e. ionization coefficient $\beta_{HI}(T_m)$ and exponential term $\exp(-h\nu_\alpha/[k_BT_m])$ in hydrogen kinetic equation of **atlant** are calculated at the temperature of matter T_m] and **recfast**. Dashed and dotted curves are partially overlapped.