IRIS Technical Note 33
Numerical Simulations General Overview

Mats Carlsson
with Viggo Hansteen, Bart De Pontieu
version 4: 28-Oct-2013

1. Introduction

This document gives general information on the *Bifrost* numerical simulations that are released as part of the IRIS project, the structure of the files provided and how to download files. There are several related IRIS Technical Notes. Derived observables (like synthetic spectra of the Mg II h and k lines) are described in ITN 35. There are several tools in Solarsoft for the visualization of the numerical simulation variables. *Crispex* is an efficient tool for the visualisation of 3D variables and can be used both for the 3D MHD variables, IRIS synthetic observables and IRIS observables. *Crispex* is described in ITN 27 (and to some extent in ITN 26 and 34). A complementary package for visualizing and analyzing the MHD variables is the *br_xmhd* package described in ITN 34.

Several simulations will be released after completion and characterization. It is important to realize that all simulations have shortcomings given the very complex nature of the solar atmosphere - especially the chromosphere. At this stage, the simulations are to be regarded as numerical experiments with given physical approximations rather than ab-initio models of the real Sun. Nevertheless we believe that these numerical experiments can be used to further our understanding of the solar atmosphere as long as the limitations are kept in mind - it is very clear from initial comparison with observations that there are many observed facts that are not reproduced by the simulations. These very discrepancies can lead to further insights since the simulations are based on very clear physical approximations and not a large set of free parameters that have been tweaked to improve the agreement with observations.

2. Bifrost

Bifrost is a general and flexible 3D Radiation MHD code developed in Oslo. The code is described in detail in Gudiksen et al (2011). In short, *Bifrost* solves the MHD equations on a staggered grid using a $5^{th}/6^{th}$ order compact finite difference scheme. The effects of radiation in the energy balance are solved for in detail by solving the radiative transfer equations along rays through the computational domain using a short-characteristic method using multi-group opacities (Nordlund 1982) modified to take into account

scattering (Skartlien 2000). See Hayek et al (2010) for a detailed description of the treatment of the radiative transfer. Chromospheric radiative losses are calculated in non-LTE using simplified recipes (Carlsson & Leenaarts 2011) based on detailed 1D full non-LTE radiative transfer simulations. Optically thin radiative losses are taken into account using tables calculated from atomic data in Chianti. Conduction becomes important at high temperatures and is included using operator splitting with an implicit formulation based on a multi-grid method. *Bifrost* is a very general modeling code and a variety of modules are available for boundary conditions and the equation-of-state. Published simulations will differ in what modules have been incorporated. For each simulation, this is further described in the section "Simulations".

3. Simulations

Simulations differ in the magnetic field configuration, the size of the computational box, the position of the lower and upper boundary, the grid resolution and the equation of state. These characteristics are encoded in the simulation "name". The first two characters give the magnetic field configuration, the next three characters give the simulation box size in Mm, the next three the horizontal grid size in km and additional characteristics are given as tags with underscores as separating character. The first simulation to be released is one where the initial magnetic field has been chosen to have two dominant polarities separated by about 8 Mm. We call this magnetic configuration "enhanced network" (en) in the following.

3.1 Simulation en024048_hion

The general characteristics of this simulation are described in detail in Carlsson et al (2013) and only a summary is given here. The computational box is 24 by 24 Mm^2 horizontally with periodic boundary conditions and extends 2.4 Mm below the visible surface (i.e., the average height where optical depth at 500 nm is unity) and 14.4 Mm above encompassing the upper part of the convection zone, the photosphere, chromosphere, transition region and corona. The computational box is 504x504x496 grid points giving 48 km resolution horizontally and a variable grid separation in the vertical direction varying from 19 km in the photosphere and chromosphere up to 5 Mm height and then increasing to 100 km at the top boundary. Both the top and bottom boundaries are transparent and no magnetic field is fed into the computational domain. Non-equilibrium ionization of hydrogen has been included following the description by Leenaarts et al (2007). The inclusion of non-equilibrium ionization of hydrogen is indicated in the name by the tag "_hion".

Each simulation is started from an initial condition that often is a result of another simulation with different approximations. The simulation en024048_hion was initialized from a hydrodynamic simulation of size 6x6x3 Mm^3 that had reached a relaxed state. This simulation reached 2.4 Mm below the visible surface but only 0.5 Mm above. The simulation was expanded horizontally (since it is periodic horizontally this just entails replicating the numerical domain to the larger size), first to 12x12 Mm^2 and then to

24x24 Mm^2. At each step the simulation was run long enough that the horizontal periodicity from the startup vanished. The relaxed hydrodynamic state of 24x24x3 Mm^3 was then expanded to 24x24x17 Mm^3 by adding a chromosphere and corona and a large scale magnetic field. The magnetic field was added by specifying the vertical field at the bottom of the computational domain with a potential field extrapolation into the rest of the domain. The field at the bottom boundary was specified to have two patches of opposite dominant polarity separated by 8 Mm. This time represents t=0 in the simulation. The simulation was run for 3020 s of solar time assuming instantaneous hydrogen ionization equilibrium before the non-equilibrium hydrogen ionization was switched on. Each timestep saved to file is called a snapshot and they are numbered from t=0 with 10s of solar time separating each snapshot. The first published snapshot is snapshot 385 at t=3850 s, which is 830 s after the switch on of the non-equilibrium hydrogen ionization when the initial startup effects have largely disappeared. The last snapshot is at t=5440 s giving a timespan of 1590 s for the published simulation. The average unsigned magnetic field strength in the photosphere is 5 mT (50 G).

Snapshots of the simulation en024048_hion (mainly snapshot 385) have been used for the following papers:

Leenaarts, J., Carlsson, M., & Rouppe van der Voort, L. (2012): "The Formation of the Hα Line in the Solar Chromosphere"

Štěpán, J. et al (2012): "The Hanle Effect of Lyα in a Magnetohydrodynamic Model of the Solar Transition Region"

de la Cruz Rodríguez, J. et al (2013): "Heating of the Magnetic Chromosphere: Observational Constraints from Ca II λ8542 Spectra"

Leenaarts et al (2013a), Leenarts et al (2013b) and Pereira et al (2013) for the study of the formation of the Mg II h and k lines.

Note that the original *Bifrost* format is with the z-axis going downwards. In order to have a right-handed coordinate system this means that the (x,y) coordinate system is mirror imaged compared with a "normal" definition. It is only when dealing with vector quantities (especially the magnetic field) that this makes a difference and the above papers dealing with intensities (all papers except Štěpán et al) show data mirror-imaged compared with the published data. The published data have the z-axis directed upwards and is right-handed with the normal (x,y) orientation.

It is important to take into account the characteristics of the simulations when analyzing them or synthetic observables derived from them. The simulations were mainly intended for chromospheric applications. Major caveats are:

1. the opacities are from old tables, basically from Gustafsson et al (1973), in order to be compatible with deep convection simulations from Stein et al. These opacities are not ideal for comparison of synthetic observables with detailed photospheric intensities.
2. there are major oscillations in the simulations, see Carlsson et al (2013) for details. The reason is that the lower boundary condition is a pressure node reflecting acoustic waves to mimic the refraction of acoustic waves in the solar deeper atmosphere. The excitation of p-modes is similar to the real Sun but the energy is spread over a very

limited set of modes giving them much larger amplitude (especially the global mode) compared with the Sun. At z=0 the amplitude of the oscillations is about 1 km/s with a period of 420 s.

3. The effective temperature is not specified in the simulations and is only set by specifying the entropy of the incoming fluid at the bottom boundary. The relaxation to a given effective temperature is a very slow process and in the en024048_hion simulation the effective temperature is typically lower than that of the Sun. The average effective temperature is 5757 K (compared to a solar value of 5880 K) with the often used snapshot 385 having Teff=5773 K and the oscillations causing an amplitude of about 30 K.
4. The height scale in the files is only approximately normalized to have a zero-point close to optical depth unity at 500 nm (the usual zero-point of height-scales). Since there are oscillations in the simulation, the average height of τ_{500}=1 varies in time with an amplitude of 60 km and a mean of 89 km.
5. The published data have all variables specified at the same location (cell-centers) instead of being on a staggered grid as in the original simulations. This means that the variables that originally are not given at cell-centers (velocities and magnetic field strength) have been interpolated to cell-centers with the same high-order interpolation scheme as used in Bifrost. This introduces interpolation noise, in particular the divergence of B is no longer zero to the machine accuracy as is the case for the original data.

4. File format

All files are in FITS format with a format similar to IRIS level 2: 3D cubes of data (x,y,z) with one variable per file. The x- and y-grids are equidistant and can be generated using the standard FITS keywords while the z-grid is non-uniform and is therefore given in a FITS extension.

4.1 Naming convention

Files have names
BIFROST_runname_variable_snap.fits

where runname is the name of the run, variable is the *Bifrost* variable name, snap is a three-digit snapnumber starting from 000. Above 999 it becomes four digits, etc

Naming convention for the runname:
idsize$dx{_tag1,}{_tag2,}...

$id is a two-character description of the region/magnetic field topology modeled. This is chosen from a set of defined values where new values need to be decided upon by the *Bifrost* consortium. So far these have been defined:
qs quiet sun
ch coronal hole

en enhanced network
ar active region
um umbra

$size is size in Mm for the longer dimension and $dx is resolution in km. Both are padded with zeros from the left to always be three digits.

examples
en024048
en024048_hion

024 is size in Mm
048 is resolution in km
_hion denotes that the simulation includes non-equilibrium ionization of hydrogen

tags can be freely constructed to increase the precision of the runname.

4.2 Centering, handedness and units

All variables are cell centered on a right-handed system with z increasing upwards. Index run the same way as the axis which means that z[1] is at the bottom and z[nz] at the top. Note that this is different from the original *Bifrost* files.

All units are SI units and given in FITS keywords (Mm, m/s, kg*m/s, T, W/m^3, nm, etc). Specifically this means that magnetic field strength is given in Tesla (1 T=10^4 G).

4.3 FITS keywords

The following is an example FITS header

```
SIMPLE  =                    T / Written by IDL:  Fri Jul 12 22:13:21 2013
BITPIX  =                  -32 / Number of bits per data pixel
NAXIS   =                    3 / Number of data axes
NAXIS1  =                  504 /
NAXIS2  =                  504 /
NAXIS3  =                  496 /
EXTEND  =                    T / FITS data may contain extensions
INSTRUME= 'Bifrost '             / Data generated by the Bifrost code
OBJECT  = 'en024048_hion'        / Bifrost run name
BTYPE   = 'lg(tg)  '             / Data variable
BUNIT   = 'K       '             / Data unit
CDELT1  =            0.0476190 / [Mm] x-coordinate increment
CDELT2  =            0.0476190 / [Mm] y-coordinate increment
CDELT3  =            0.0971498 / [Mm] (non-uniform) z-coordinate increment
CRPIX1  =                    1 / Reference pixel x-coordinate
CRPIX2  =                    1 / Reference pixel y-coordinate
CRPIX3  =                    1 / Reference pixel z-coordinate
CRVAL1  =              0.00000 / [Mm] Position ref-pixel x-coordinate
CRVAL2  =              0.00000 / [Mm] Position ref-pixel y-coordinate
CRVAL3  =             -2.44401 / [Mm] Position ref-pixel z-coordinate
```

```
CTYPE1  = 'x       '           / [Mm] Label for x-coordinate
CTYPE2  = 'y       '           / [Mm] Label for y-coordinate
CTYPE3  = 'z       '           / [Mm] Label for z-coordinate
CUNIT1  = 'Mm      '           / Unit for x-coordinate
CUNIT2  = 'Mm      '           / Unit for y-coordinate
CUNIT3  = 'Mm      '           / Unit for z-coordinate
RUNID   = 'Bifrost_cb24bih'    / Run ID for identification of input files
ELAPSED =              3850.00 / [s] Time of snapshot
DATA_LEV=                    2 / Data level
ZTAU51  =            0.0613866 / [Mm] Average height of tau(500nm)=1
ORIGIN  = ' ITA/Oslo'          / Origin of data
COMMENT Variables from .idl file:
MX      =                  504 / mx
MY      =                  504 / my
MZ      =                  496 / mz
MB      =                    5 / mb
NSTEP   =              5000000 / nstep
NSTPSTRT=               823373 / nstepstart
DEBUG   =                    0 / debug
PERIOD_X=                    1 / periodic_x
PERIOD_Y=                    1 / periodic_y
PERIOD_Z=                    0 / periodic_z
NDIM    =                    3 / ndim
U_L     =          1.00000E+08 / u_l
U_T     =              100.000 / u_t
U_R     =          1.00000E-07 / u_r
U_P     =              100000. / u_p
U_U     =          1.00000E+06 / u_u
U_KR    =             0.100000 / u_kr
U_EE    =          1.00000E+12 / u_ee
U_E     =              100000. / u_e
U_TE    =          1.00000E+11 / u_te
U_TG    =              9681.00 / u_tg
U_B     =              1121.00 / u_b
MESHFILE= 'cb24bih.mesh'       / meshfile
DX      =            0.0476200 / dx
DY      =            0.0476200 / dy
DZ      =            0.0850300 / dz
CDT     =             0.300000 / cdt
DT      =          5.24900E-05 / dt
T       =              38.5000 / t
TSTPDB  =                    0 / timestepdebug
NU1     =           0.0500000 / nu1
NU2     =            0.300000 / nu2
NU3     =            0.700000 / nu3
NU_R_XY =             0.00000 / nu_r_xy
NUR_XYK =                    0 / nu_r_xy_k
NU_R    =            0.200000 / nu_r
NU_R_MIN=           0.0200000 / nu_r_min
NU_R_K  =                  360 / nu_r_k
NU_EE_XY=             0.00000 / nu_ee_xy
NU_EE   =            0.200000 / nu_ee
GRAV    =            -2.74000 / grav
ETA3    =            0.200000 / eta3
CA_MAX  =             100.000 / ca_max
MHDDEBUG=                    0 / mhddebug
DO_MHD  =                    1 / do_mhd
MHDCLEAN=                   -1 / mhdclean
```

```
ONE_FILE=                     0 / one_file
SNAPNAME= 'cb24bih '            / snapname
ISNAP   =                   385 / isnap
LRG_MEM =                     1 / large_memory
NSNAP   =               1000000 / nsnap
NSCR    =                   200 / nscr
AUX     = 'p tg i1 '            / aux
DTSNAP  =              0.100000 / dtsnap
NEWAUX  =                     0 / newaux
DTSCR   =               1000.00 / dtscr
TSNAP   =               38.5000 / tsnap
TSCR    =               0.00000 / tscr
BDRYCHK =                     0 / boundarychk
MAX_R   =                     5 / max_r
SMOOTH_R=                     3 / smooth_r
QMAX    =               8.00000 / qmax
NONEQ   =                     0 / noneq
GAMMA   =               1.66700 / gamma
TABFILE = 'tabparam.in'         / tabinputfile
DO_RAD  =                     1 / do_rad
DTRAD   =            0.00300000 / dtrad
QUADRATU=                     3 / quadrature
ZREFINE =                     1 / zrefine
MAXITER =                    60 / maxiter
TAUSTRM =          1.00000E-05 / taustream
ACCURACY=            0.00100000 / accuracy
STRCTINT=                     1 / strictint
LINEAR  =                     1 / linear
MONOTON =                     1 / monotonic
MAXBIN  =                     4 / maxbin
DUALSWEE=                     1 / dualsweep
TEFF    =               5773.00 / teff
TIMING  =                     0 / timing
DO_HION =                     1 / do_hion
HOLDPOP =                     1 / hionhasoldpops
DBHION  =                     1 / debug_hion
LTESNAPS=                     0 / ltesnaps
FRSTSNAP=                     0 / firstsnap
LASTSNAP=                     0 / lastsnap
SOLVE_GZ=                     0 / solve_gz
VDAMP   =               5.00000 / vdamp
HATOMFIL= 'H_6.atom.ccpol'      / hionatomfile
HNEETABF= 'opctab_hion.dat'     / hionneetabfile
SPITZER = 'impl    '            / spitzer
SPITZAMP=               1.00000 / spitzer_amp
TGB0    =          1.00000E+06 / tgb0
TGB1    =          1.00000E+06 / tgb1
TAU_TG  =            0.00500000 / tau_tg
FXGRADTG=                     0 / fix_grad_tg
DOGENRAD=                     1 / do_genrad
DBGENRAD=                     0 / debug_genrad
BCTYPLOW= 'mf      '            / bctypelower
TAU_BCL =               1.00000 / tau_bcl
TAUEEBCL=               100.000 / tau_ee_bcl
TAUD2BCL=               100.000 / tau_d2_bcl
TAUD5BCL=               1.00000 / tau_d5_bcl
TAUD6BCL=               1.00000 / tau_d6_bcl
TAUD7BCL=               1.00000 / tau_d7_bcl
```

```
TAUD8BCL=              1.00000 / tau_d8_bcl
S0      =              9.83205 / s0
E0      =            0.0700428 / e0
R0      =            0.0186682 / r0
CS0     =             0.654463 / cs0
P0      =           0.00481020 / p0
NSMOOBCL=                  100 / nsmooth_bcl
NAVERBCL=                   -1 / naver_bcl
NCLEABCL=                  300 / nclean_bcl
NCLEALBL=                   -4 / nclean_lbl
NCLEAUBL=                    1 / nclean_ubl
BXL     =              0.00000 / bxl
TAU_BXL =              100000. / tau_bxl
T_BDRY  =              1.00000 / t_bdry
RBOT    =              280.874 / rbot
EBOT    =              2900.00 / ebot
BX0     =              0.00000 / bx0
BY0     =              0.00000 / by0
X0_BCU  =              99.0000 / x0_bcu
X1_BCU  =             -99.0000 / x1_bcu
Y0_BCU  =              99.0000 / y0_bcu
Y1_BCU  =             -99.0000 / y1_bcu
UZ_BCU  =             0.100000 / uz_bcu
STRTB   = 'n       '           / strtb
NCLEABCU=                   -1 / nclean_bcu
COMMENT $Id: mpi.f90,v 1.67 2010/02/22 21:49:40 boris Exp $
COMMENT $Id: main.f90,v 1.79 2010/04/13 15:56:05 hayek Exp $
COMMENT $Id: solar.f90,v 1.11 2010/01/11 12:26:25 boris Exp $
COMMENT $Id: stagger_mesh_mpi.f90,v 1.49 2010/06/16 08:25:01 boris Exp $
COMMENT $Id: io.f90,v 1.85 2010/02/14 11:56:26 viggoh Exp $
COMMENT $Id: mhd_mpi-diff.f90,v 1.29 2010/07/28 13:38:44 matsc Exp $
COMMENT $Id: hyman_mpi-diff.f90,v 1.8 2010/04/13 13:05:50 boris Exp $
COMMENT $Id: math_mpi-diff.f90,v 1.15 2010/07/14 14:36:14 jorritl Exp $
COMMENT $Id: quench3_mpi.f90,v 1.9 2008/05/14 15:21:11 juanms Exp $
COMMENT $Id: square_gas_mpi.f90,v 1.32 2009/10/14 12:06:42 jorritl Exp $
COMMENT $Id: radiation_GS_mpi.f90,v 1.47 2010/07/12 09:06:31 jorritl Exp $
COMMENT $Id: timing_mpi.f90,v 1.11 2010/04/13 13:00:17 boris Exp $
COMMENT $Id: tr_extras_mpi.f90,v 1.7 2008/11/05 15:38:57 viggoh Exp $
COMMENT $Id: spitzer_conductivity_mpi.f90,v 1.41 2010/01/12 12:04:55 boris Exp $
COMMENT $Id: genrad_mpi.f90,v 1.16 2010/04/27 14:52:19 matsc Exp $
COMMENT $Id: standard_boundaries.f90,v 1.60 2010/06/16 11:34:44 matsc Exp $
COMMENT $Id: bc_lower_magnetic-diff.f90,v 1.20 2010/06/04 14:11:06 viggoh Exp $
COMMENT $Id: bc_upper_damp.f90,v 1.19 2010/04/27 14:38:06 matsc Exp $
COMMENT $Id: hion_mpi.f90,v 1.42 2010/06/24 13:03:53 jorritl Exp $
COMMENT $Id: tr_boundaries.f90,v 1.46 2010/06/16 10:18:18 matsc Exp $
COMMENT Non-uniform z-coordinate
DATE    = '12-Jul-Fri'         / Creation UTC (CCCC-MM-DD) date of FITS header
COMMENT FITS (Flexible Image Transport System) format is defined in 'Astronomy
COMMENT and Astrophysics', volume 376, page 359; bibcode 2001A&A...376..359H
END
```

The first set of keywords (until ORIGIN) are FITS standard keywords with explanation in the comment field with the following exceptions:

```
BTYPE   = 'lg(tg)  '           / Data variable
RUNID   = 'Bifrost_cb24bih'    / Run ID for identification of input files
ELAPSED =              3850.00 / [s] Time of snapshot
DATA_LEV=                    2 / Data level
ZTAU51  =            0.0613866 / [Mm] Average height of tau(500nm)=1
```

BTYPE gives what variable is in the data section of the FITS file. RUNID is a local ID to identify the name of the run on the local servers in Oslo and serves to enable tracing the history of the run, input EOS tables etc. ELAPSED is the time since t=0 of the simulation. DATA_LEV is data level where level2 indicates 3-dimensional data (x,y,z) and level3 is 4-dimensional (x,y,z,t). ZTAU51 is the average height of tau(500nm)=1 and may be missing from the FITS file since it is a derived quantity that comes from either a synthetic observable run or from looking up opacities in the EOS tables. Note that the height scale is not changed during a run and the average height of tau(500nm)=1 is not zero but varies with time when there are global oscillations present.

After the standard FITS keywords there is a block with all internal Bifrost variables that are written to the Bifrost internal .idl file. These variable names may be longer than the FITS keyword limit of eight characters and therefore the original Bifrost variable name follows as a comment. The meaning of these variables may be found in the Bifrost documentation and only a few are of general interest:

`ISNAP` is the snap number that is also part of the file-name

`TEFF` is the effective temperature of this particular snapshot. An attempt has been made to get the solar effective temperature but this is very hard to achieve. The effective temperature of a simulation is affected by the entropy of the incoming fluid at the bottom boundary but the response is very slow such that only after many simulations one may get something similar to the solar conditions. When comparing photospheric lines with observations it is important to bear this in mind.

Variables that start with `NU` are viscocity parameters. If these are changed in the middle of a run (e.g. to get passed a situation with strong gradients that lead to numerical instabilities) there may be transients generated. Especially for wave-studies it is important to check that the excitation of waves is not caused by such transients.

Following the block of .idl file Bifrost variables there is a block of comments giving the version number of the Bifrost subroutines that were linked into the executable at the time of the writing of the snapshot file. Code changes may also give rise to transients and suspicious behavior in the time-evolution of variables should be checked against possible code changes.

5. How to download files

Files (called level2 files) can be downloaded from http://sdc.uio.no/search/simulations. In the GUI one chooses which simulation (to begin with only en024048_hion is available but more will come soon), which variables and which snapshot numbers one wishes to download. Note that one quickly runs into large data-volumes, each file is 480 MB in size.

Snapshots available: 385-544
Variables available:

variable name	explanation
lgr	^{10}log(mass density)
ux	bulk velocity in x
uy	bulk velocity in y
uz	bulk velocity in z
lge	^{10}log(internal energy)
bx	magnetic field strength in x
by	magnetic field strength in x
bz	magnetic field strength in z
lgne	^{10}log(electron density)
lgp	^{10}log(gas pressure)
lgtg	^{10}log(temperature)

6. Visualization with Crispex

Crispex can be used to visualize a single snapshot with its three-dimensional datacube. Another use of Crispex is to visualize the time-dependent behavior, corresponding to level 3 files in IRIS. Crispex uses [x,y,lambda,t] (im_file) and [lambda,t,x,y] (sp-file) cubes. For Bifrost variables this corresponds to [x,y,z,t] (im-file) and [z,t,x,y] (sp-file). Level 3 Bifrost files are made from level 2 files with
br_make_fits_level3,`run_name,it,cvar`
where `it` is an array with snap-numbers and `cvar` is the variable name (e.g. “lgtg”). There is a need for speed so it is possible to choose a limited height-range and even data scaled to 16 bit integer or byte. Also log of a variable that is not logarithmic in the level 2 file is possible. See documentation of br_make_fits_level3 for a complete list of keywords.
The sp-file is made from transposing the im-file using the routine
br_transpose_fits_level3.pro

Extra keywords for the im-file:

```
'CDELT4  ',dt,' [s] (non-uniform) t-coordinate increment'
'CRPIX4  ',1,' Reference pixel t-coordinate'
'CRVAL4  ',t[0],' [s] Time pixel 1 t-coordinate'
'CTYPE4  ','t',' [s] Label for t-coordinate'
'CUNIT4  ','s',‘ Unit for t-coordinate’
```

Keywords added if scaling

```
‘BZERO   ‘   true_value = BZERO + BSCALE*array_value
‘BSCALE  ’
```

Changed keywords

```
‘DATA_LEV’,3,‘ Data level’
‘ELAPSED ’ not used

‘BTYPE   ’ gets ‘lg ‘ prepended if log variable is asked for
           if scaling is combined with log then “true_value”
           is the log value
```

Extension 2: t-coordinate

```
'EXTNAME ','t axis’,‘ Extension name’
‘BTYPE   ‘,‘time’,‘ Data variable’
'BUNIT   ','s’,‘ Unit for t-coordinate’
```

Extension 3: snap-coordinate

```
'EXTNAME ',‘isnap axis’,‘ Extension name’
‘BTYPE   ‘,‘snap number’,‘ Data variable’
'BUNIT   ',’ ’,‘ Unit for isnap-coordinate’
```

7. Credit line

Papers published based on the simulations should cite the code description paper (Gudiksen et al 2011) and the paper describing the particular simulation (for en024048_hion that is Carlsson et al 2013).

7. References

Carlsson, M., Hansteen, V.H., Gudiksen, B.V., Leenaarts, J., De Pontieu, B, 2013, A&A, in prep.
de la Cruz Rodríguez, J., De Pontieu, B., Carlsson, M., Rouppe van der Voort, L.H.M., ApJ 764,11
Gudiksen, B.V., Carlsson, M., Hansteen, V.H., et al. 2011, A&A, 531, A154
Gustafsson, B.G. 1973, Uppsala Astron. Obs. Ann., 5, 6
Hayek, W., Asplund, M., Carlsson, M., et al. 2010, A&A, 517, A49
Leenaarts, J., Carlsson, M., & Rouppe van der Voort, L. 2012, ApJ, 749, 13
Leenaarts J., Carlsson M., Hansteen V.H., Rutten R.J., 2007, A&A, 473, 625
Leenaarts, J., Pereira, T.M.D., Carlsson, M., Uitenbroek, H., & De Pontieu, B. 2013a, ApJ, 772:89
—. 2013b, ApJ, 772:90
Nordlund A., 1982, A&A, 107, 1
Pereira, T.M.D., Leenaarts, J., De Pontieu, B, Carlsson, M., Uitenbroek, H. 2013, ApJ, in prep
Skartlien R., 2000, ApJ, 536, 465
Štěpán, J.; Trujillo Bueno, J.; Carlsson, M.; Leenaarts, J., 2012, ApJ 758, 43