Proyecto de Modelado Matemático I: Visualización en VisIt

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Planteamiento del problema

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Newtonian CAFE: a new ideal MHD code to study the solar atmosphere

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ABSTRACT

We present a new code designed to solve the equations of classical ideal magnetohydrodynamics (MHD) in three dimensions, submitted to a constant gravitational field. The purpose of the code centres on the analysis of solar phenomena within the photosphere–corona region. We present 1D and 2D standard tests to demonstrate the quality of the numerical results obtained with our code. As solar tests we present the transverse oscillations of Alfvénic pulses in coronal loops using a 2.5D model, and as 3D tests we present the propagation of impulsively generated MHD-gravity waves and vortices in the solar atmosphere. The code is based on high-resolution shock-capturing methods, uses the Harten–Lax–van Leer–Einfeldt (HLLE) flux formula combined with Minmod, MC, and WENO5 reconstructors. The divergence free magnetic field constraint is controlled using the Flux Constrained Transport method.

Key words: MHD – methods: numerical – Sun: atmosphere.

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CrossMark

Magnus: A New Resistive MHD Code with Heat Flow Terms

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Abstract

We present a new magnetohydrodynamic (MHD) code for the simulation of wave propagation in the solar atmosphere, under the effects of electrical resistivity—but not dominant—and heat transference in a uniform 3D grid. The code is based on the finite-volume method combined with the HLLE and HLLC approximate Riemann solvers, which use different slope limiters like MINMOD, MC, and WENO5. In order to control the growth of the divergence of the magnetic field, due to numerical errors, we apply the Flux Constrained Transport method, which is described in detail to understand how the resistive terms are included in the algorithm. In our results, it is verified that this method preserves the divergence of the magnetic fields within the machine round-off error ($\sim 1 \times 10^{-12}$). For the validation of the accuracy and efficiency of the schemes implemented in the code, we present some numerical tests in 1D and 2D for the ideal MHD. Later, we show one test for the resistivity in a magnetic reconnection process and one for the thermal conduction, where the temperature is advected by the magnetic field lines. Moreover, we display two numerical problems associated with the MHD wave propagation. The first one corresponds to a 3D evolution of a vertical velocity pulse at the photosphere–transition–corona region, while the second one consists of a 2D simulation of a transverse velocity pulse in a coronal loop.

Key words: magnetohydrodynamics (MHD) – methods: numerical – Sun: atmosphere

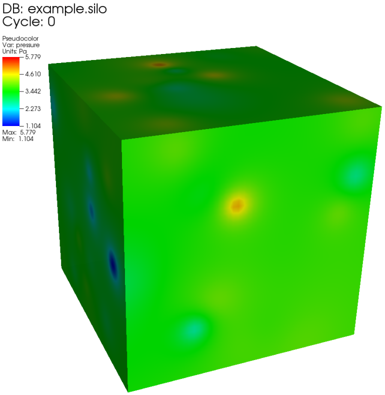
1. Introduction

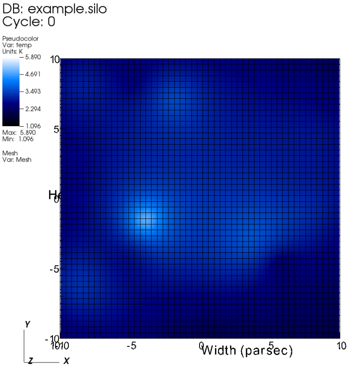
The theory of magnetohydrodynamics—the study of interactions between magnetic fields and conductive fluids in low frequencies—is of great importance for understanding the dynamics of the plasma in the solar atmosphere (Priest & Hood 1991). Since the plasma in this region is highly

atmosphere (Jess et al. 2012a). Complete reviews of observations of magnetohydrodynamic waves in solar regions like the corona, sunspots, prominences, coronal mass ejections, solar flares, and solar winds can be found in Nakariakov & Verwichte (2005), Khomenko & Collados (2015), Okamoto et al. (2007), Vršnak et al. (2013), Shibata & Magara (2011), and Ofman (2010), respectively.

```
(base) paula@PaulaCW:~/prom/Graphs_ASCII$ head -25 primitivas_1.xyzl

 #Time =    0.0000000000000000


   0.0000000000000000      -0.50000000000000000      -0.50000000000000000       3.0300707122200770E-006   9.9999758799911391E-015   1.0000023485319312E-014
  9.9999997540632175E-015   299.99983692554611         7.0897999763653063E-023   7.0897999763653063E-023   5.0000001419004654E-003
   0.0000000000000000      -0.50000000000000000      -0.47999999999999998       3.0300707122200770E-006   9.9998374590737456E-015   1.0000168665552601E-014
  1.0000000189603918E-014   299.99983692554611         7.0897999763653063E-023   7.0897999763653063E-023   5.0000001419004654E-003
   0.0000000000000000      -0.50000000000000000      -0.46000000000000002       3.0300707122200770E-006   9.9989808468348144E-015   1.0001107112894802E-014
  1.0000003004945944E-014   299.99983692554611         7.0897999763653063E-023   7.0897999763653063E-023   5.0000001419004654E-003
   0.0000000000000000      -0.50000000000000000      -0.44000000000000000       3.0300707122200770E-006   9.9941040676192648E-015   1.0006699245196090E-014
  1.0000019781342848E-014   299.99983692554611         7.0897999763653063E-023   7.0897999763653063E-023   5.0000001419004654E-003
   0.0000000000000000      -0.50000000000000000      -0.41999999999999998       3.0300707122200770E-006   9.9685720085807909E-015   1.0037413580362885E-014
  1.0000111924348348E-014   299.99983692554611         7.0897999763653063E-023   7.0897999763653063E-023   5.0000001419004654E-003
   0.0000000000000000      -0.50000000000000000      -0.40000000000000002       3.0300707122200770E-006   9.8456996948181114E-015   1.0192874667451618E-014
  1.0000578307609614E-014   299.99983692554611         7.0897999763653063E-023   7.0897999763653063E-023   5.0000001419004654E-003
   0.0000000000000000      -0.50000000000000000      -0.38000000000000000       3.0300707122200770E-006   9.3024279254236336E-015   1.0917857257959950E-014
  1.0002753255381139E-014   299.99983692554611         7.0897999763653063E-023   7.0897999763653063E-023   5.0000001419004654E-003
   0.0000000000000000      -0.50000000000000000      -0.35999999999999999       3.0300707122200770E-006   7.0968887834391687E-015   1.4032098153788638E-014
  1.0012095978068625E-014   299.99983692554611         7.0897999763653063E-023   7.0897999763653063E-023   5.0000001419004654E-003
   0.0000000000000000      -0.50000000000000000      -0.33999999999999997       3.0300707122200770E-006  -1.1186569161339387E-015   2.6350965269109879E-014
  1.0049052579414590E-014   299.99983692554611         7.0897999763653063E-023   7.0897999763653063E-023   5.0000001419004654E-003
   0.0000000000000000      -0.50000000000000000      -0.32000000000000001       3.0300707122200770E-006  -2.9173474951067055E-014   7.1208553797846292E-014
  1.0183625345000799E-014   299.99983692554611         7.0897999763653063E-023   7.0897999763653063E-023   5.0000001419004654E-003
   0.0000000000000000      -0.50000000000000000      -0.29999999999999999       3.0300707122200770E-006  -1.1690786257281141E-013   2.2151310344176631E-013
  1.0634538993932558E-014   299.99983692554611         7.0897999763653063E-023   7.0897999763653063E-023   5.0000001419004654E-003
   0.0000000000000000      -0.50000000000000000      -0.28000000000000003       3.0300707122200770E-006  -3.6783910560619354E-013   6.8471268769845656E-013
  1.2024137746702629E-014   299.99983692554611         7.0897999763653063E-023   7.0897999763653063E-023   5.0000001419004654E-003
   0.0000000000000000      -0.50000000000000000      -0.26000000000000001       3.0300707122200770E-006  -1.0231425810445261E-012   1.9968126549272344E-012
  1.5960437648388964E-014   299.99983692554611         7.0897999763653063E-023   7.0897999763653063E-023   5.0000001419004654E-003
   0.0000000000000000      -0.50000000000000000      -0.23999999999999999       3.0300707122200770E-006  -2.5823440342231712E-012   5.4107167369864601E-012
  2.6202149894566641E-014   299.99983692554611         7.0897999763653063E-023   7.0897999763653063E-023   5.0000001419004654E-003
   0.0000000000000000      -0.50000000000000000      -0.21999999999999997       3.0300707122200770E-006  -5.9528653076985586E-012   1.3561966607367233E-011
  5.0655899505708960E-014   299.99983692554611         7.0897999763653063E-023   7.0897999763653063E-023   5.0000001419004654E-003
   0.0000000000000000      -0.50000000000000000      -0.20000000000000001       3.0300707122200770E-006  -1.2546531168509553E-011   3.1401327920163171E-011
  1.0417398344409679E-013   299.99983692554611         7.0897999763653063E-023   7.0897999763653063E-023   5.0000001419004654E-003
   0.0000000000000000      -0.50000000000000000      -0.17999999999999999       3.0300707122200770E-006  -2.4154398808302749E-011   6.7133330021864337E-011
  2.1136998974920029E-013   299.99983692554611         7.0897999763653063E-023   7.0897999763653063E-023   5.0000001419004654E-003
   0.0000000000000000      -0.50000000000000000      -0.15999999999999998       3.0300707122200770E-006  -4.2387838862377795E-011   1.3250324644362160E-010
  4.0747973901447202E-013   299.99983692554611         7.0897999763653063E-023   7.0897999763653063E-023   5.0000001419004654E-003
   0.0000000000000000      -0.50000000000000000      -0.14000000000000001       3.0300707122200770E-006  -6.7587161875994187E-011   2.4142843526995708E-010
  7.3425530549347846E-013   299.99983692554611         7.0897999763653063E-023   7.0897999763653063E-023   5.0000001419004654E-003
   0.0000000000000000      -0.50000000000000000      -0.12000000000000000       3.0300707122200770E-006  -9.7447395985511123E-011   4.0608248327132344E-010
  1.2282174494975776E-012   299.99983692554611         7.0897999763653063E-023   7.0897999763653063E-023   5.0000001419004654E-003
(base) paula@PaulaCW:~/prom/Graphs_ASCII$
```

VisIt


DB: example.silo
Cycle: 0
Pseudocolor
Var: pressure
Units: Pa
5.779
4.610
3.442
2.273
1.104
Max: 5.779
Min: 1.104

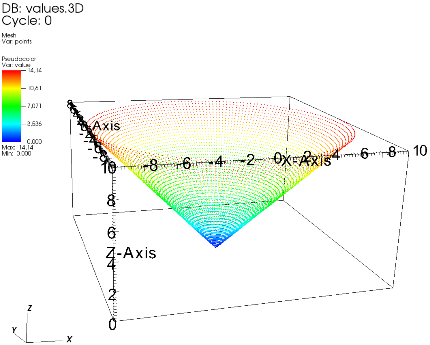

DB: example.silo
Cycle: 0
Pseudocolor
Var: temp
Units: K
5.890
4.691
3.493
2.294
1.096
Max: 5.890
Min: 1.096
Mesh
Var: Mesh
Width (parsec)
-10
-5
0
5
10
Y
X
Z

Solución 1

```
from __future__ import print_function
import os
from astropy.io import ascii

def ascii2hdf5(inputfile, outputfile, clobber=False, overwrite=True,
               verbose=False):
    """Convert a file to hdf5 using compression and path set to data"""
    if verbose:
        print('converting {} to {}'.format(inputfile, outputfile))

    tbl = ascii.read(inputfile)
    try:
        tbl.write(outputfile, format='hdf5', path='data', compression=True,
                  overwrite=overwrite)
    except:
        print('problem with {}'.format(inputfile))
        return

    if clobber:
        os.remove(inputfile)
        if verbose:
            print('removed {}'.format(inputfile))

    return
```

Solución 2

```
import math
n = 10000
f = open("values.3D", "wt")
f.write("x y z value\n");
for i in range(n):
    t = float(i) / float(n-1)
    angle = t * (math.pi * 2.) * 50.
    r = t * 10.
    x = r * math.cos(angle)
    y = r * math.sin(angle)
    z = t * 10.
    value = math.sqrt(x*x + y*y + z*z)
    f.write("%g %g %g %g\n" % (x,y,z,value))
f.close()
```



```python
import sys
import numpy as np

# Se importa el archivo con los datos correspondientes
# a las dimensiones y tiempos de las corridas
filedata = open('linput_plots.par', 'r')

lines = filedata.readlines()
# Se asignan la variables del archivo filedata en
# las variables correspondientes
xmin = float(lines[1].split('=')[1])
xmax = float(lines[2].split('=')[1])
ymin = float(lines[3].split('=')[1])
ymax = float(lines[4].split('=')[1])
zmin = float(lines[5].split('=')[1])
zmax = float(lines[6].split('=')[1])
Nxx = int(lines[7].split('=')[1])
Nyy = int(lines[8].split('=')[1])
Nzz = int(lines[9].split('=')[1])
Ntt = int(lines[10].split('=')[1])
courant = float(lines[11].split('=')[1])
every3D = float(lines[14].split('=')[1])

# Se cierra el archivo
filedata.close()

# Se calculan los pasos espaciales y temporales
dx  = (xmax - xmin)/float(Nxx)
dy  = (ymax - ymin)/float(Nyy)
dz  = (zmax - zmin)/float(Nzz)
dt = courant * min(dx,dy,dz)
```

```python
# Se importa el archivo con los datos de las corridas correspondientes a las variables
# densidad, velocidad en x, y, z, presion y campo magnetico en x, y, z
f = open('primitivas_1.xyzl', 'r')

# Se crea la funcion 'extraer' para tomar determinado tiempo y variable del archivo f
def extraer(parametro):

    # Se leen las entradas para reconocer la variable y tiempo a extraer
    variable = str(parametro.split('-')[0])
    bloque = format(int(parametro.split('-')[1]), '02')

    # Se calcula el tiempo real que se esta extrayendo
    t = dt*float(bloque)*every3D

    # Se valida la infomacion acerca de la variable, el bloque de tiempo y el tiempo
    # real que se esta extrayendo
    print 'Extrayendo la variable',variable,'en el bloque',bloque,'en',t, 'segundos.'

    # Se saltan las lineas correspondientes a los tiempos anteriores al que se requiere
    skip = int((((Nyy+2)*(Nxx+1)+1)*(Nzz+1)+4)*int(bloque))
    print 'Se saltan', skip, 'lineas.'
    for a in range (0,skip+3):
        f.readline()

    # Se crea un archivo nuevo llamado por el nombre de la variable y el bloque a extraer
    w = open('%s_b%s.3D'%(variable,bloque), 'wt')
    # Se escribe el encabezado necesario para que VisIt pueda leer los archivos ASCII
    w.write('x y z %s\n'%variable);
```

```python
# Se leen las lineas de la misma manera como fueron salvadas y se reescriben
# los datos requeridos en el archivo w
for i in range (0,Nzz+1):
    f.readline()
    for j in range (0,Nxx+1):
        f.readline()
        for k in range (0,Nyy+1):
            z, x, y, rho, vx, vy, vz, press, Bx, By, Bz = f.readline().split()
            if (variable == 'v'):
                v = np.sqrt(float(vx)**2+float(vy)**2+float(vz)**2)
                w.write('%g %g %g %g\n' %(float(x),float(y),float(z),float(v)))
            elif (variable == 'B'):
                B = np.sqrt(float(Bx)**2+float(By)**2+float(Bz)**2)
                w.write('%g %g %g %g\n' %(float(x),float(y),float(z),float(B)))
            elif (variable == 'rho'):
                w.write('%g %g %g %g\n' %(float(x),float(y),float(z),float(rho)))
            elif (variable == 'vx'):
                w.write('%g %g %g %g\n' %(float(x),float(y),float(z),float(vx)))
            elif (variable == 'vy'):
                w.write('%g %g %g %g\n' %(float(x),float(y),float(z),float(vy)))
            elif (variable == 'vz'):
                w.write('%g %g %g %g\n' %(float(x),float(y),float(z),float(vz)))
            elif (variable == 'press'):
                w.write('%g %g %g %g\n' %(float(x),float(y),float(z),float(press)))
            elif (variable == 'Bx'):
                w.write('%g %g %g %g\n' %(float(x),float(y),float(z),float(Bx)))
            elif (variable == 'By'):
                w.write('%g %g %g %g\n' %(float(x),float(y),float(z),float(By)))
            elif (variable == 'Bz'):
                w.write('%g %g %g %g\n' %(float(x),float(y),float(z),float(Bz)))

# Se cierran ambos archivos
w.close()
f.close()
```

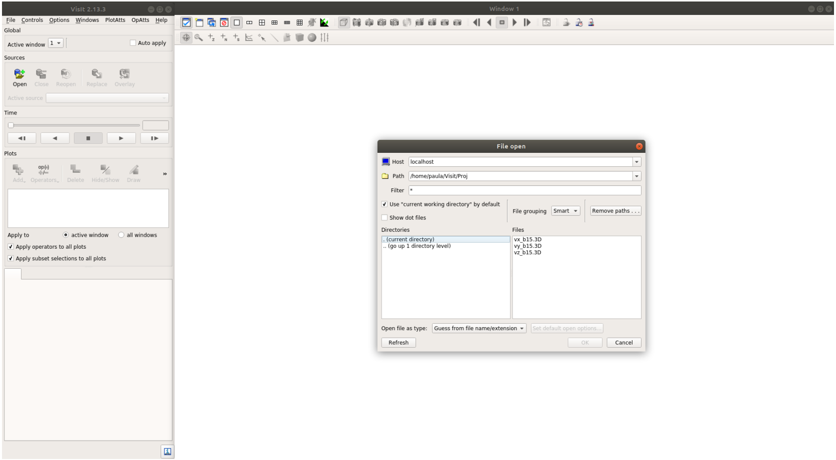
```python
# Se utilizan estas 3 lineas para llamar la funcion
# e ingresar la variable y bloque a salvar desde la terminal
method_name = sys.argv[1]
parameter_name = sys.argv[2]
getattr(sys.modules[__name__], method_name)(parameter_name)
```

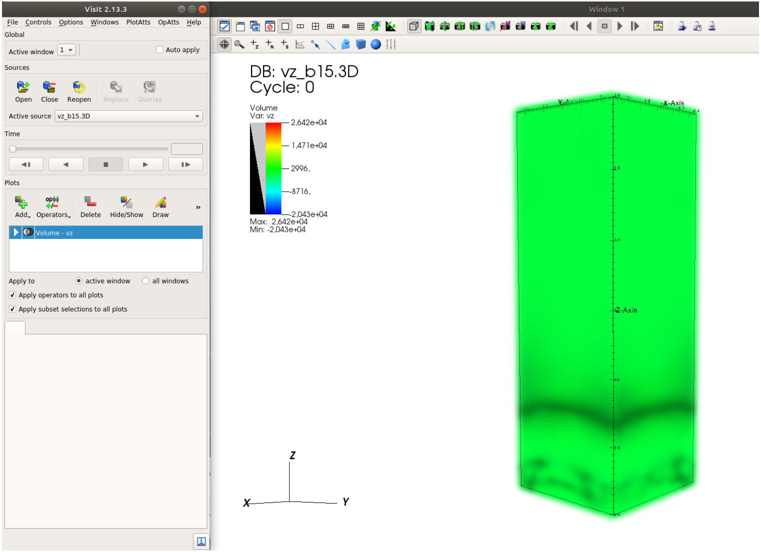
Archivos resultantes

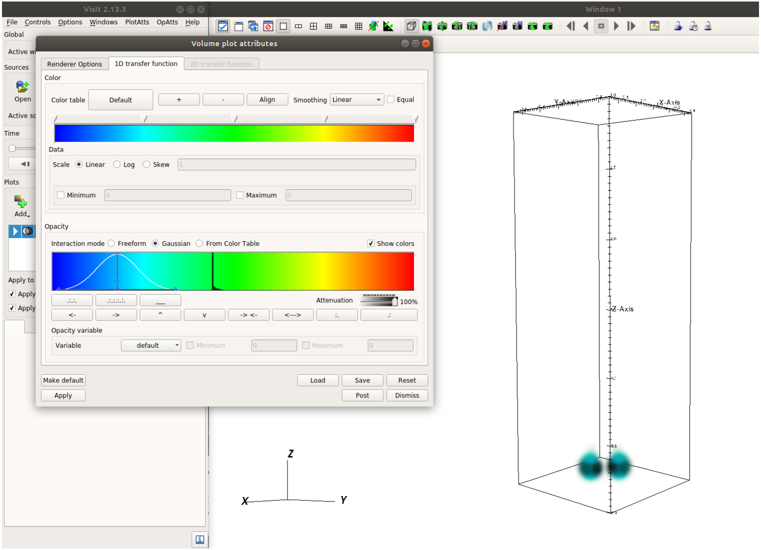
```
(base) paula@PaulaCW:~/prom/Graphs_ASCII$ head -25 vz_b15.3D
x y z vz
-0.5 -0.5 0 1e-14
-0.5 -0.48 0 1e-14
-0.5 -0.46 0 1e-14
-0.5 -0.44 0 1.00001e-14
-0.5 -0.42 0 1.00008e-14
-0.5 -0.4 0 1.00041e-14
-0.5 -0.38 0 1.00195e-14
-0.5 -0.36 0 1.00859e-14
-0.5 -0.34 0 1.03482e-14
-0.5 -0.32 0 1.13036e-14
-0.5 -0.3 0 1.45048e-14
-0.5 -0.28 0 2.437e-14
-0.5 -0.26 0 5.23151e-14
-0.5 -0.24 0 1.25024e-13
-0.5 -0.22 0 2.9863e-13
-0.5 -0.2 0 6.78572e-13
-0.5 -0.18 0 1.43959e-12
-0.5 -0.16 0 2.83184e-12
-0.5 -0.14 0 5.15173e-12
-0.5 -0.12 0 8.65852e-12
-0.5 -0.1 0 1.34386e-11
-0.5 -0.08 0 1.92576e-11
-0.5 -0.06 0 2.54771e-11
-0.5 -0.04 0 3.11156e-11
```

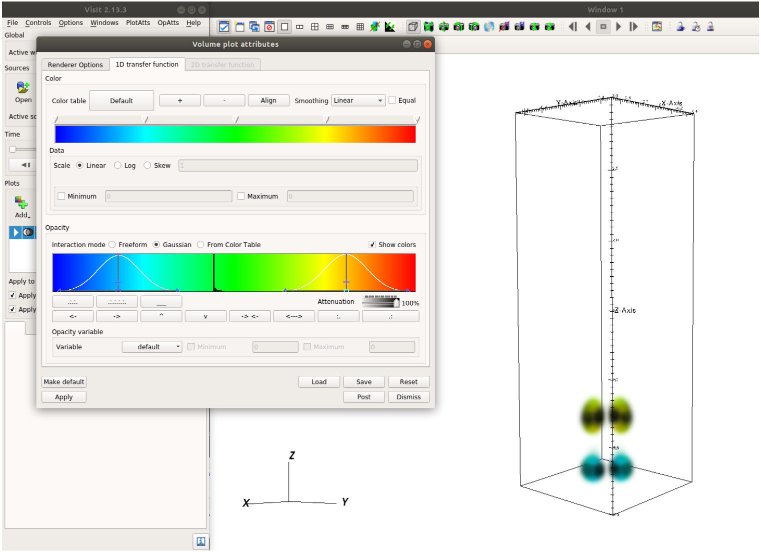
Script en bash

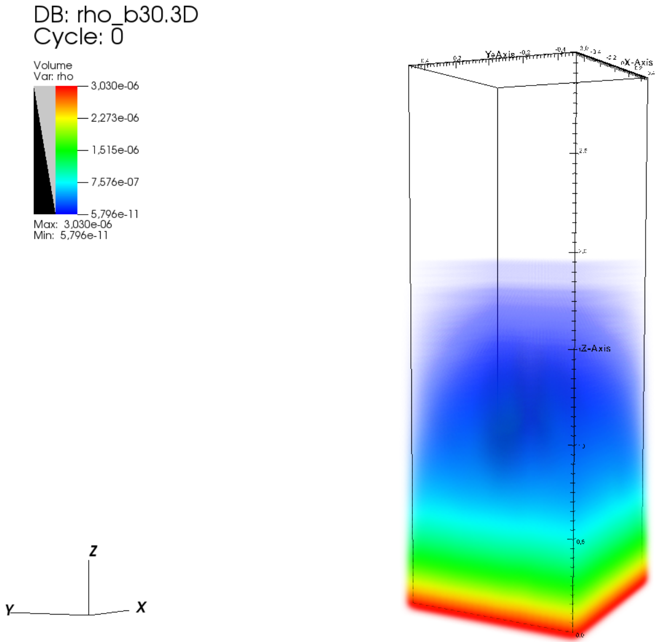
```
(base) paula@PaulaCW:~/prom/Graphs_ASCII$ cat myscript.sh
#!/usr/bin/env bash

rm *.3D

v=${1?Error: Ingrese otra variable}
b=${2?Error: Ingrese otro bloque}

python extractor.py extraer $v-$b

cp *.3D ../../../../../Visit/Proj/

cd
./visit
```

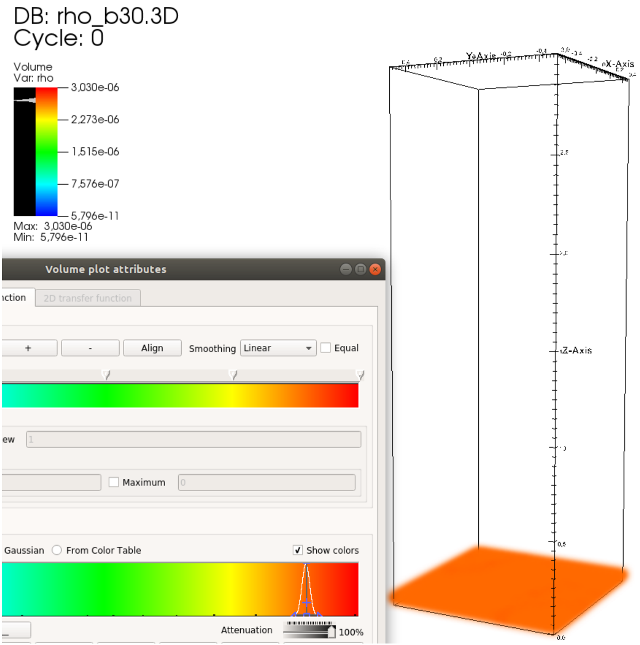

VisIt 2.13.3
File Controls Options Windows PlotAtts OpAtts Help
Global
Active window 1
Auto apply
Sources
Open Close Reopen Replace Overlay
Active source
Time
Plots
Add Operators Delete Hide/Show Draw
Apply to active window all windows
Apply operators to all plots
Apply subset selections to all plots
Window 1
File open
Host localhost
Path /home/paula/Visit/Proj
Filter *
Use "current working directory" by default
Show dot files
File grouping Smart
Remove paths . . .
Directories
. (current directory)
.. (go up 1 directory level)
Files
vx_b15.3D
vy_b15.3D
vz_b15.3D
Open file as type: Guess from file name/extension
Set default open options...
Refresh
OK
Cancel


VisIt 2.13.3
File Controls Options Windows PlotAtts OpAtts Help
Global
Active window 1
Auto apply
Sources
Open Close Reopen Replace Overlay
Active source vz_b15.3D
Time
Plots
Add Operators Delete Hide/Show Draw
Volume - vz
Apply to active window all windows
Apply operators to all plots
Apply subset selections to all plots
Window 1
DB: vz_b15.3D
Cycle: 0
Volume
Var: vz
2,642e+04
1,471e+04
2996,
-8716,
-2,043e+04
Max: 2,642e+04
Min: -2,043e+04
Z-Axis
X-Axis
Z
X
Y


VisIt 2.13.3
File Controls Options Windows PlotAtts OpAtts Help
Window 1
Volume plot attributes
Renderer Options
1D transfer function
2D transfer function
Color
Color table
Default
Align
Smoothing
Linear
Equal
Data
Scale
Linear
Log
Skew
Minimum
Maximum
Opacity
Interaction mode
Freeform
Gaussian
From Color Table
Show colors
Attenuation
100%
Opacity variable
Variable
default
Make default
Apply
Load
Save
Reset
Post
Dismiss
Z-Axis
X-Axis
Y-Axis
Z
X
Y


VisIt 2.13.3
Window 1
File Controls Options Windows PlotAtts OpAtts Help
Volume plot attributes
Renderer Options
1D transfer function
2D transfer function
Color
Color table
Default
Align
Smoothing
Linear
Equal
Data
Scale
Log
Skew
Minimum
Maximum
Opacity
Interaction mode
Freeform
Gaussian
From Color Table
Show colors
Attenuation
100%
Opacity variable
Variable
default
Make default
Apply
Load
Save
Reset
Post
Dismiss
Y-Axis
X-Axis
Z-Axis
Z
X
Y


DB: rho_b30.3D
Cycle: 0
Volume
Var: rho
3,030e-06
2,273e-06
1,515e-06
7,576e-07
5,796e-11
Max: 3,030e-06
Min: 5,796e-11
Y-Axis
X-Axis
Z-Axis
Z
Y
X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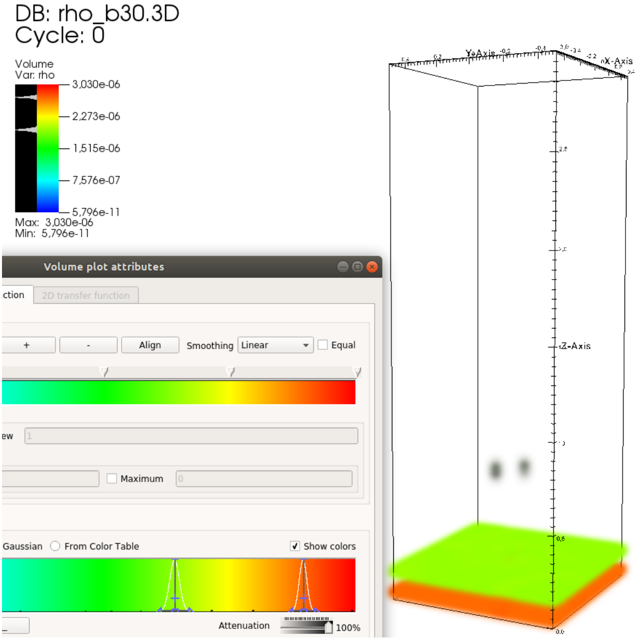
2,273e-06
1,515e-06
7,576e-07
5,796e-11
Max: 3,030e-06
Min: 5,796e-11
Volume plot attributes
2D transfer function
Align
Smoothing
Linear
Equal
Maximum
Gaussian
From Color Table
Show colors
Attenuation
100%
Y-Axis
X-Axis
Z-Axis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Cycle: 0
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Var: rho
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1,515e-06
7,576e-07
5,796e-11
Max: 3,030e-06
Min: 5,796e-11
Volume plot attributes
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2D transfer function
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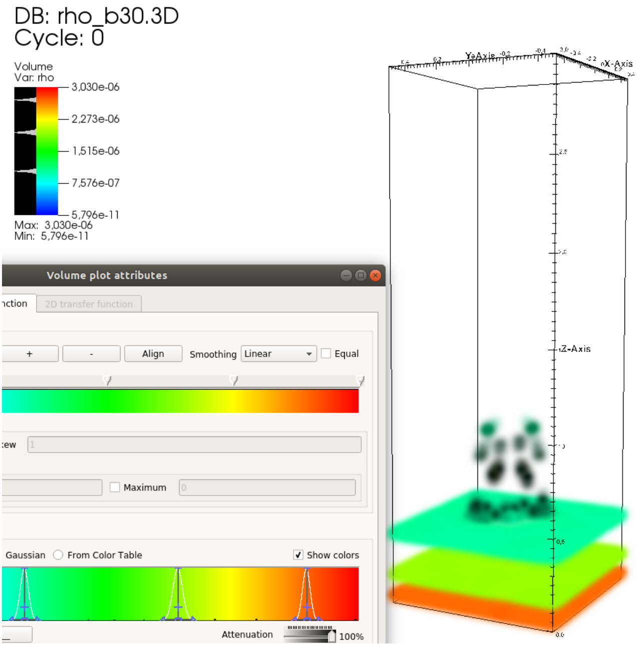
Align
Smoothing
Linear
Equal
ew
1
Maximum
0
Gaussian
From Color Table
Show colors
Attenuation
100%
Y-Axis
X-Axis
Z-Axis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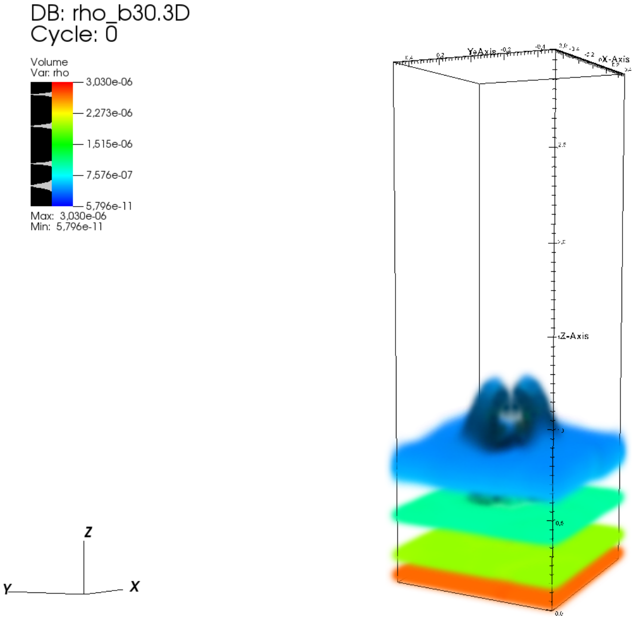
Max: 3,030e-06
Min: 5,796e-11
Volume plot attributes
2D transfer function
Align
Smoothing
Linear
Equal
Maximum
Gaussian
From Color Table
Show colors
Attenuation
100%
Z-Axis
X-Axis
Y-Axis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7,576e-07
5,796e-11
Max: 3,030e-06
Min: 5,796e-11
Y-Axis
X-Axis
Z-Axis
Z
Y
X

¡GRACIAS!