HAZEL2: "inversion" mode

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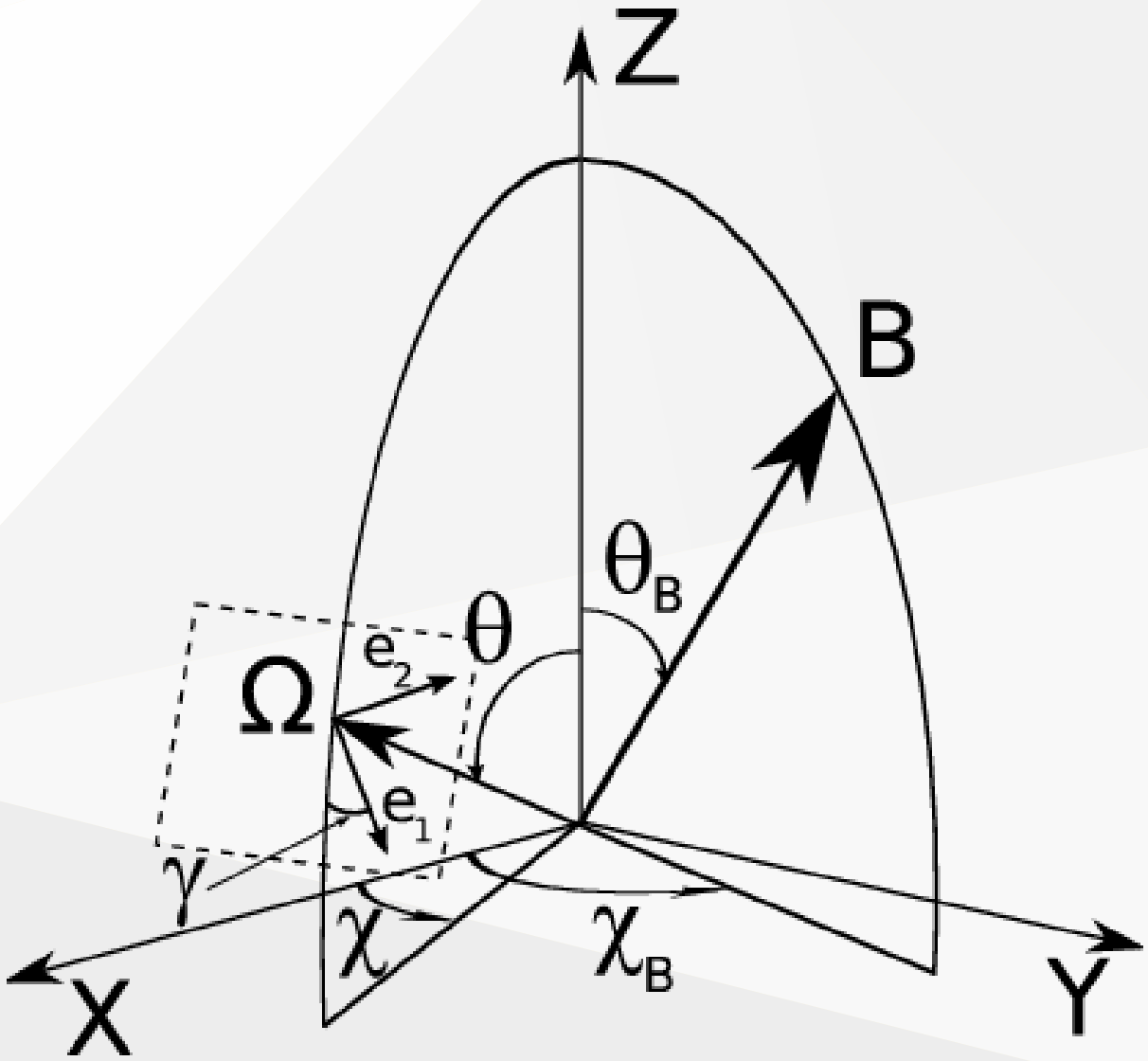
Basic Functions of HAZEL2

- **Synthesis** (Core function)
- **Inversion** (Call synthesis repeatedly, and return the values with best match.)

Input ➡️ Inversion

- Stokes profiles (I, Q, U, V)
- Observer angle (θ, χ, γ)

📖Hazel2 documents > 5.3.1. The geometry for the scattering event



Inversion ➡ Output

- Magnetic field vector (B_x, B_y, B_z)
- Thermal velocity affecting the width of the line
- Bulk velocity of the plasma leading to a redshift / blueshift
- Optical depth of the line
- Line damping parameter

Steps to invert

1. Data file
2. Initial guess file
3. Configuration file
4. Invert
5. Read results

1 Data file

```
noise = 2e-4
f = open('10830aStokes.1d', 'wb')
f.write(b'# LOS theta_LOS, phi_LOS, gamma_LOS\n')
f.write(b'0 0 90\n')
f.write(b'\n')
f.write(b'# Boundary condition I/Ic(mu=1), Q/Ic(mu=1), U/Ic(mu=1), V/Ic(mu=1)\n')
f.write(b'1 0 0 0\n')
f.write(b'\n')
f.write(b'# SI SQ SU SV sigmaI sigmaQ sigmaU sigmaV\n')
tmp = np.vstack([stokes, noise*np.ones(stokes.shape)])
np.savetxt(f, tmp.T)
f.close()
```

Noise can be different for all Stokes, all wavelength.

1 Data file

```
%cat  -n 10830aStokes.1d

     1  # LOS theta_LOS, phi_LOS, gamma_LOS
     2  0 0 90
     3
     4  # Boundary condition I/Ic(mu=1), Q/Ic(mu=1), U/Ic(mu=1), V/Ic(mu=1)
     5  1 0 0 0
     6
     7  # SI SQ SU SV sigmaI sigmaQ sigmaU sigmaV
     8  9.952280784594604857e-01 -1.148041469718687782e-04
        8.399747497915658083e-05 -1.290206569171977371e-05
        1.668915300086476863e-04 1.668915300086476863e-04
        1.668915300086476863e-04 1.668915300086476863e-04
     9  9.951098576610630797e-01 1.623758783952787175e-04
        -8.213450435604240031e-05 3.815948168220573725e-05
        1.668915300086476863e-04 1.668915300086476863e-04
```

2️⃣ Initial guess file

hazel2/examples/chromospheres/model_chromosphere.1d

```
%cat -n model_chromosphere.1d

     1    Bx     By    Bz    tau      v       deltav     beta     a      ff
     2  0    0    10.0    1.0    0.0       8.0        1.0     0.5     1
```

📝 Initial values should be within ranges.

📝 A very good guess (e.g. do a second round using the results of first round as initial values) cost less computation time and may lead to slightly better fitting results.

3 Configuration file

hazel2/examples/configurations

3.1 Working mode

```
%cat -n conf.ini
     1  # Hazel configuration File
     3  [Working mode]
     4  Output file = output.h5
     5  Number of cycles = 2
```

Number of cycles to carry out during inversion. Cycle 1 is to invert Stokes I only. Cycle 2 is to invert Stokes Q, U, and V.

3.2 Spectral regions

```
14  [Spectral regions]
15      [[Region 1]]
16      Name = spec1
17      Wavelength = 10828, 10831, 50
18      Topology = ch1
19      Observations file = '10830aStokes.1d'
20      Weights Stokes I = 1, 0
21      Weights Stokes Q = 0, 1
22      Weights Stokes U = 0, 1
23      Weights Stokes V = 0, 1
```

Weights are float numbers. E.g. Use 0.5 for noisy Stokes V.

3.3 Atmospheres

```
30  [Atmospheres]
32      [[Chromosphere 1]]
33      Name = ch1          # Name of the atmosphere component
34      Spectral region = spec1
35      Height = 3              # Height of the slab
36      Line = 10830                            # 10830, 5876
37      Reference atmospheric model = 'model_chromosphere.1d'
```

Relative path refers to the current folder. HAZEL goes to the folder that contains the configuration file to find files such as 'model_chromosphere.1d'.

Ranges

```
40          [[[Ranges]]]
39          Bx      = -1000, 1000
40          By      = -1000, 1000
41          Bz      = -1000, 1000
44          tau     = 0.01, 2
45          v       = -9.0, 9.0
46          deltav  = 3.0, 15.0
47          beta    = 1, 2
48          a       = 0, 1.5
49          ff      = 1, 2
```

📝 Narrower ranges may be faster, with more accurate results.

📝 If some values in your results are very close to range limits: Make sure initial values are in range. Expand ranges and redo inversion.

Nodes

```
51          [[[Nodes]]]
52          Bx      = 0, 1
53          By      = 0, 1
54          Bz      = 0, 1
55          tau     = 1, 0
56          v       = 1, 0
57          deltav  = 1, 0
58          beta    = 0, 0
59          a       = 1, 0
60          ff      = 0, 0
```

In the first cycle, use Stokes I to invert tau, v, deltav, a.
In the last cycle, use Stokes Q, U, and V to invert B.
beta and ff are not changed. 0 or 1 for chromosphere.

4 Invert

```
modi = hazel.Model('conf.ini', working_mode='inversion')
modi.read_observation()
modi.open_output()
modi.invert()
modi.write_output()
modi.close_output()
```

```
# OSError: Unable to create file (unable to truncate a file which is already open)
```

To fix this error, in 5, explicitly close .h5 files when no longer in use.

5 Read results

Print model results.

```
res = h5py.File('output.h5', 'r')  # explicitly close when no longer in use.
sto = ['Bx','By','Bz','tau','v','deltav','beta','a','ff']
stp = ''
for i in sto:
    sti = res['ch1'][i][0,0,0]
    stp += ', '+i+':'+f'{sti:.2f}'
chi2 = res['spec1']['chi2'][0,0,0]
print(stp[2:]+', chi2:'+f'{chi2:.2f}')
# Bx:-199.58, By:53.06, Bz:100.03, tau:1.02, v:-3.01,
# deltav:6.13, beta:1.00, a:0.47, ff:1.00, chi2:0.61
```

5 Read results

Plot fitting lines.

```
for i in range(4):
    plt.subplot(221+i)
    plt.plot(ms.wavelength_axis, res['spec1']['stokes'][0,0,i])
    plt.xlabel('Wavelength [$\AA$]')
    plt.ylabel(iq[i]+'/Ic')
res.close()
```

Explicitly close .h5 files when no longer in use.

📝 This series of presentations focus on **basic functions** of HAZEL2. **Everything required** for HAZEL2 synthesis and inversion has been shown.

📖 You will find things that are not covered in the presentations (E.g. .weights file, extra lines in configuration file). They are **optional**, and more information can be found in Hazel2 documents.

💻 Now, let's piece all the code snippets together.
👉hazel2simple.ipynb