# Error Analysis Module for SFIT4

# Ingredients

Main Ingredients:

- Gain matrix
- K matrix
- AB matrices
  - AB = Dy * Kb
- sb.ctl

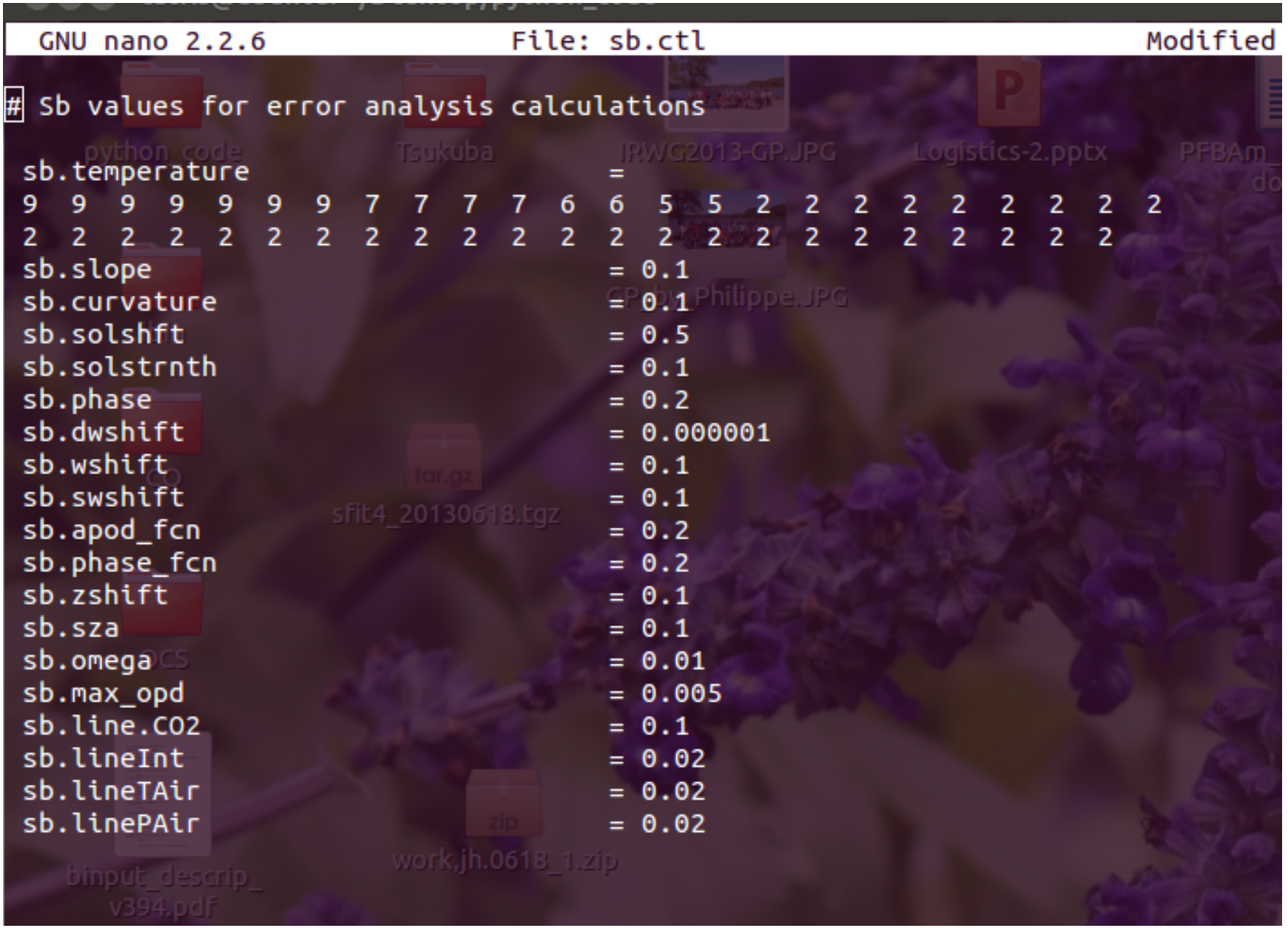
Optional Ingredients:

- Smeas matrix
  - But if not output seinv is required
- Ssmooth matrix
  - But if not output we sa.complete is required
- Target Averaging Kernel (ak.target)

Other required information:

- sfit4.ctl: numner of gases, which kb are calculated...
- rprfs.table for airmass
- statevec for a priori and retrieved profiles

# sb.ctl



```
 GNU nano 2.2.6                File: sb.ctl                          Modified

# Sb values for error analysis calculations

sb.temperature                                =
9  9  9  9  9  9  9  7  7  7  7  6  6  5  5  2  2  2  2  2  2  2  2  2
2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
sb.slope                                      = 0.1
sb.curvature                                  = 0.1
sb.solshft                                    = 0.5
sb.solstrnth                                  = 0.1
sb.phase                                      = 0.2
sb.dwshift                                    = 0.000001
sb.wshift                                     = 0.1
sb.swshift                                    = 0.1
sb.apod_fcn                                   = 0.2
sb.phase_fcn                                  = 0.2
sb.zshift                                     = 0.1
sb.sza                                        = 0.1
sb.omega                                      = 0.01
sb.max_opd                                    = 0.005
sb.line.CO2                                   = 0.1
sb.lineInt                                    = 0.02
sb.lineTAir                                   = 0.02
sb.linePAir                                   = 0.02
```

# Python code

- Main code: error_analysis.py
- Matrix file reader: file_read.py
  - will change name
- Ctl file reader: sfit4_ctl_simple.py
  - will change name
  - based on Mathias Palm code provided at error analysis workshop
  - may get updated
- Statevec reader: read_statevec.py
  - Mathias Palm code provided at error analysis workshop
- rprfs reader: read_rprfs.py

# Calculates Errors

$$\begin{aligned}
\mathbf{A} = \frac{\partial \hat{\mathbf{x}}}{\partial \mathbf{x}} &= \frac{\partial}{\partial \mathbf{x}} \left[ \mathbf{x}_a + (\mathbf{K}^T \mathbf{S}_\epsilon^{-1} \mathbf{K} + \mathbf{S}_a^{-1})^{-1} \mathbf{K}^T \mathbf{S}_\epsilon^{-1} (\mathbf{K}\mathbf{x} - \mathbf{K}\mathbf{x}_a) \right] \\
&= (\mathbf{K}^T \mathbf{S}_\epsilon^{-1} \mathbf{K} + \mathbf{S}_a^{-1})^{-1} \mathbf{K}^T \mathbf{S}_\epsilon^{-1} \mathbf{K} \\
&= \mathbf{G}\mathbf{K}
\end{aligned}$$

$$\begin{aligned}
\hat{\mathbf{x}} - \mathbf{x} &= \mathbf{x}_a + \mathbf{G}_y \mathbf{K}_x (\mathbf{x} - \mathbf{x}_a) + \mathbf{G}_y \mathbf{K}_b (\mathbf{b} - \hat{\mathbf{b}}) + \mathbf{G}_y \Delta \mathbf{f}(\mathbf{x}, \mathbf{b}, \mathbf{b}') + \mathbf{G}_y \boldsymbol{\epsilon} - \mathbf{x} \\
&= \mathbf{x}_a - \mathbf{x} + \mathbf{A}\mathbf{x} - \mathbf{A}\mathbf{x}_a + \mathbf{G}_y \mathbf{K}_b (\mathbf{b} - \hat{\mathbf{b}}) + \mathbf{G}_y \Delta \mathbf{f}(\mathbf{x}, \mathbf{b}, \mathbf{b}') + \mathbf{G}_y \boldsymbol{\epsilon} \\
&= (\mathbf{A} - \mathbf{I}_n)\mathbf{x} - (\mathbf{A} - \mathbf{I}_n)\mathbf{x}_a + \mathbf{G}_y \mathbf{K}_b (\mathbf{b} - \hat{\mathbf{b}}) + \mathbf{G}_y \Delta \mathbf{f}(\mathbf{x}, \mathbf{b}, \mathbf{b}') + \mathbf{G}_y \boldsymbol{\epsilon} \\
&= (\mathbf{A} - \mathbf{I}_n)(\mathbf{x} - \mathbf{x}_a) + \mathbf{G}_y \mathbf{K}_b (\mathbf{b} - \hat{\mathbf{b}}) + \mathbf{G}_y \Delta \mathbf{f}(\mathbf{x}, \mathbf{b}, \mathbf{b}') + \mathbf{G}_y \boldsymbol{\epsilon}. \qquad (8.121
\end{aligned}$$

- The second term, $\mathbf{G}_y \mathbf{K}_b (\mathbf{b} - \hat{\mathbf{b}})$, is known as the model parameter error. The error covariance of this contribution is $\mathbf{G}_y \mathbf{K}_b \mathbf{S}_b \mathbf{K}_b^{\mathrm{T}} \mathbf{G}_y^{\mathrm{T}}$ where $\mathbf{S}_b = \langle (\mathbf{b} - \hat{\mathbf{b}})(\mathbf{b} - \hat{\mathbf{b}})^{\mathrm{T}} \rangle$. Typically $\mathbf{S}_b$ is a diagonal matrix with the elements of the diagonal being the uncertainties in the model parameters.

- The final term, $\mathbf{G}_y \boldsymbol{\epsilon}$, is known as the retrieval noise. It can be interpreted as the measurement noise projected into state space and its covariance is represented by $\mathbf{G}_y \mathbf{S}_y \mathbf{G}_y^{\mathrm{T}}$.

# Output to screen

Column amount =

DOFS (total column) =

Sm (%) =

Ss (%) =

Sint1 (retrieval params) (%) =

Sint2 (intf. spec.) (%) =

S_Temperature (%) =

Kb for BckGrdSlp is 0, S_BckGrdSlp not calculated

Kb for BckGrdCur is 0, S_BckGrdCur not calculated

Kb for SolLnShft is 0, S_SolLnShft not calculated

Kb for SolLnStrn is 0, S_SolLnStrn not calculated

Kb for SPhsErr is 0, S_SPhsErr not calculated

Kb for IWNumShft is 0, S_IWNumShft not calculated

Kb for EmpApdFcn is 0, S_EmpApdFcn not calculated

Kb for EmpPhsFnc is 0, S_EmpPhsFnc not calculated

Kb for SWNumShft is 0, S_SWNumShft not calculated

S_SZA (%) =

Kb for FOV is 0, S_omega not calculated

S_max_opd (%) =

S_LineInt (%) =

S_LineTAir (%) =

S_LinePAir (%) =

Random error (measurement, interference, temperature, pointing, ILS) (%) =

Systematic error (spectral line intensity and air broadened half width) (%) =

# Still to come...

- Output to file output?
  - Would love input from the group.
  - For HDF file?
- Work out proper units for the Sbs
  - percent? natural units?
  - Will include document with distribution
  - comments in sample sb.ctl file
- Make sure errors are calculated properly
  - go back to the math!
  - Will include with distribution
- Recipes for defining Sb
  - Already started by Martine, but completion  will be the goal of the next error workshop