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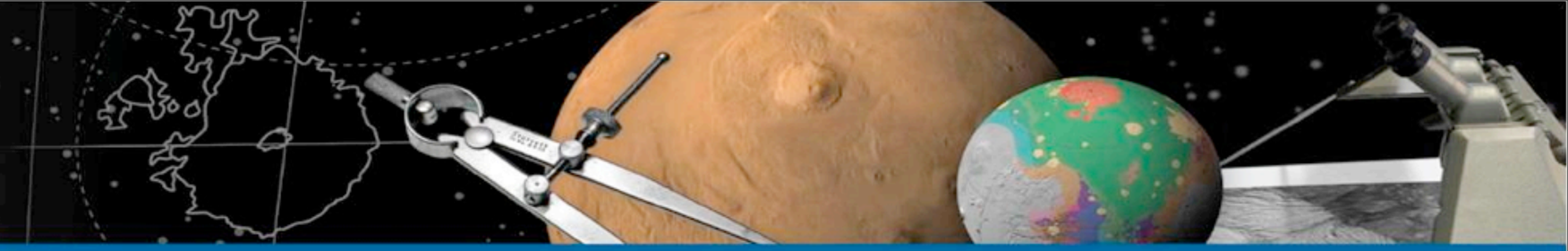


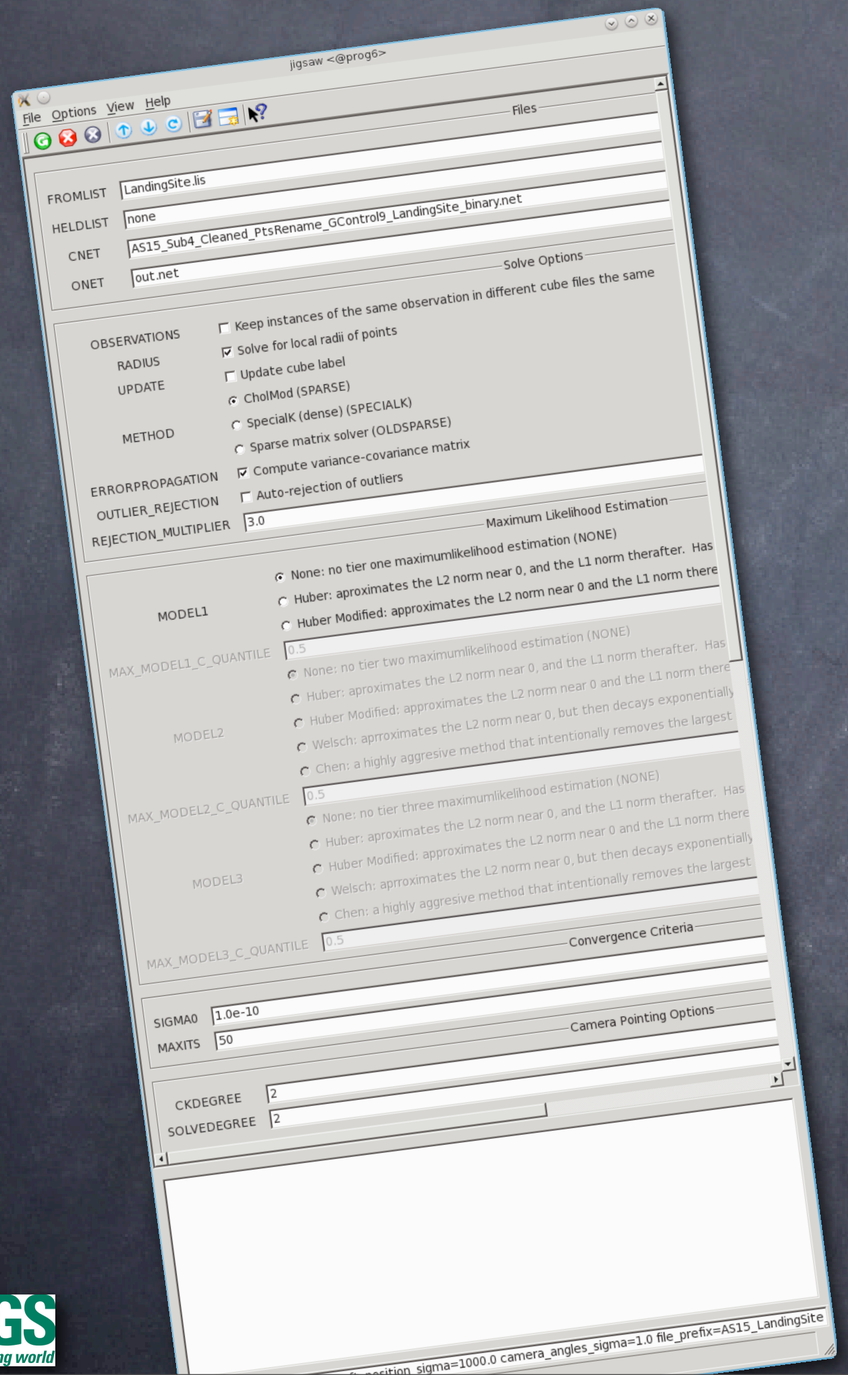
ASTROGEOLOGY SCIENCE CENTER

Jigsaw

The ISIS Bundle Adjustment for Extraterrestrial Photogrammetry

Kenneth Edmundson
U.S. Geological Survey
Astrogeology / Geomatics Team

Least Squares Bundle Adjustment



Input

- Image Measurements.
- Initial values for image pointing/position and ground point coordinates.
- 'a priori' precisions for above parameters if available.

Output

- Refined image pointing/position and ground point coordinates.
- Their uncertainties.
- Solution statistics.

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The Mathematical Model

$$x - x_p + \delta_x = -c\frac{m_{11}(X - X_c) + m_{12}(Y - Y_c) + m_{13}(Z - Z_c)}{m_{31}(X - X_c) + m_{32}(Y - Y_c) + m_{33}(Z - Z_c)}$$

$$y - y_p + \delta_y = -c\frac{m_{21}(X - X_c) + m_{22}(Y - Y_c) + m_{23}(Z - Z_c)}{m_{31}(X - X_c) + m_{32}(Y - Y_c) + m_{33}(Z - Z_c)}$$

The Collinearity Condition

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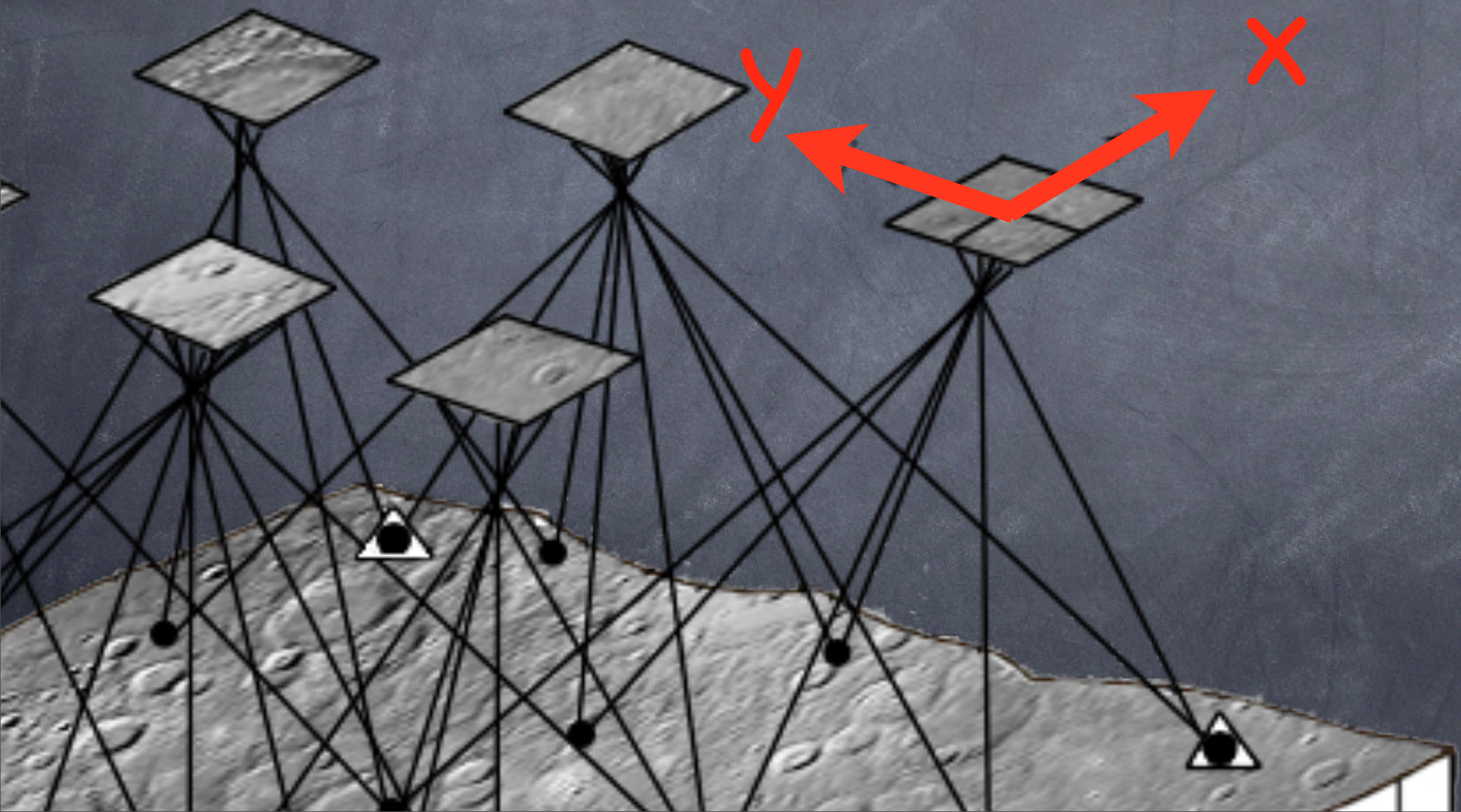
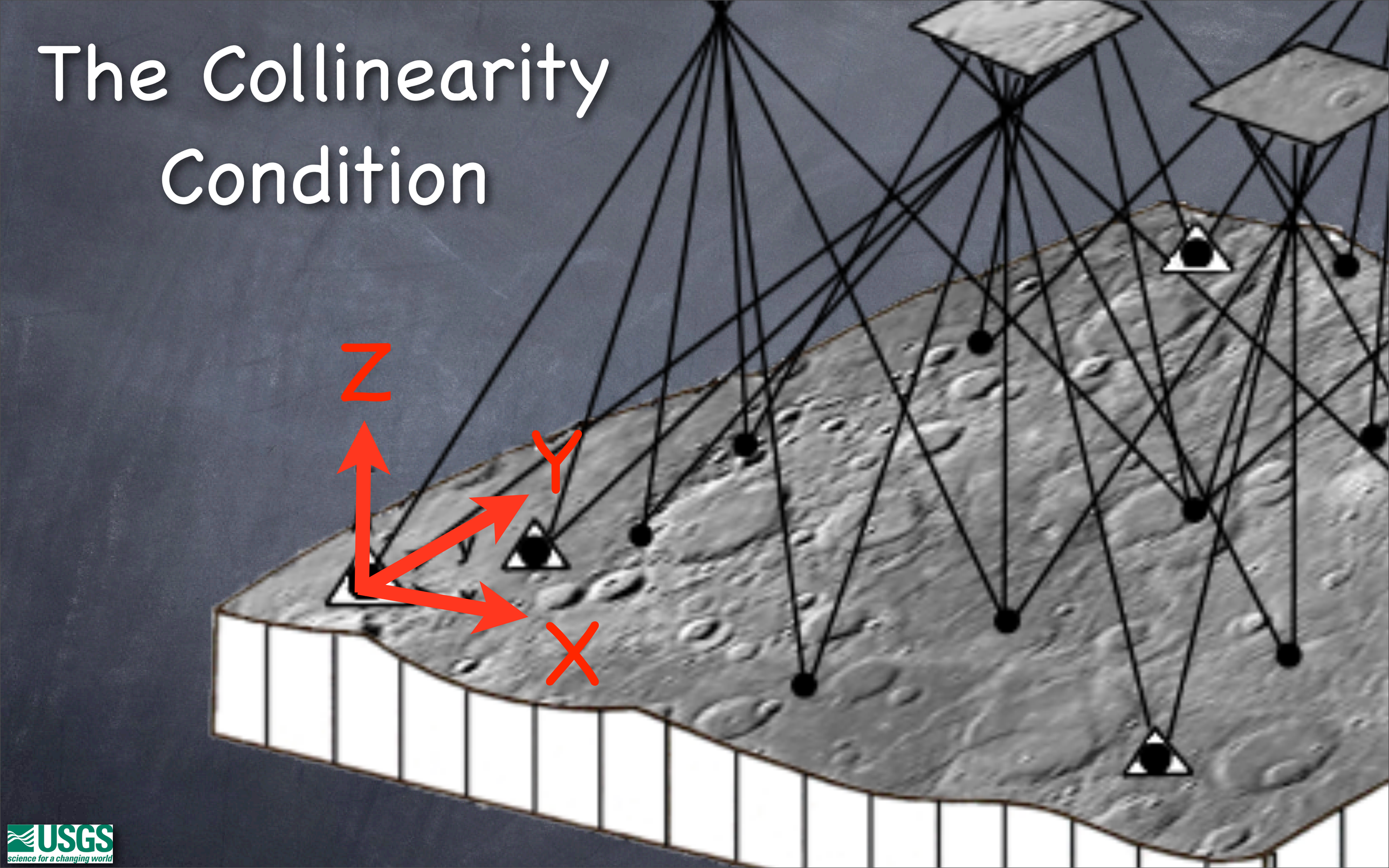
The Collinearity Condition



The Collinearity Condition



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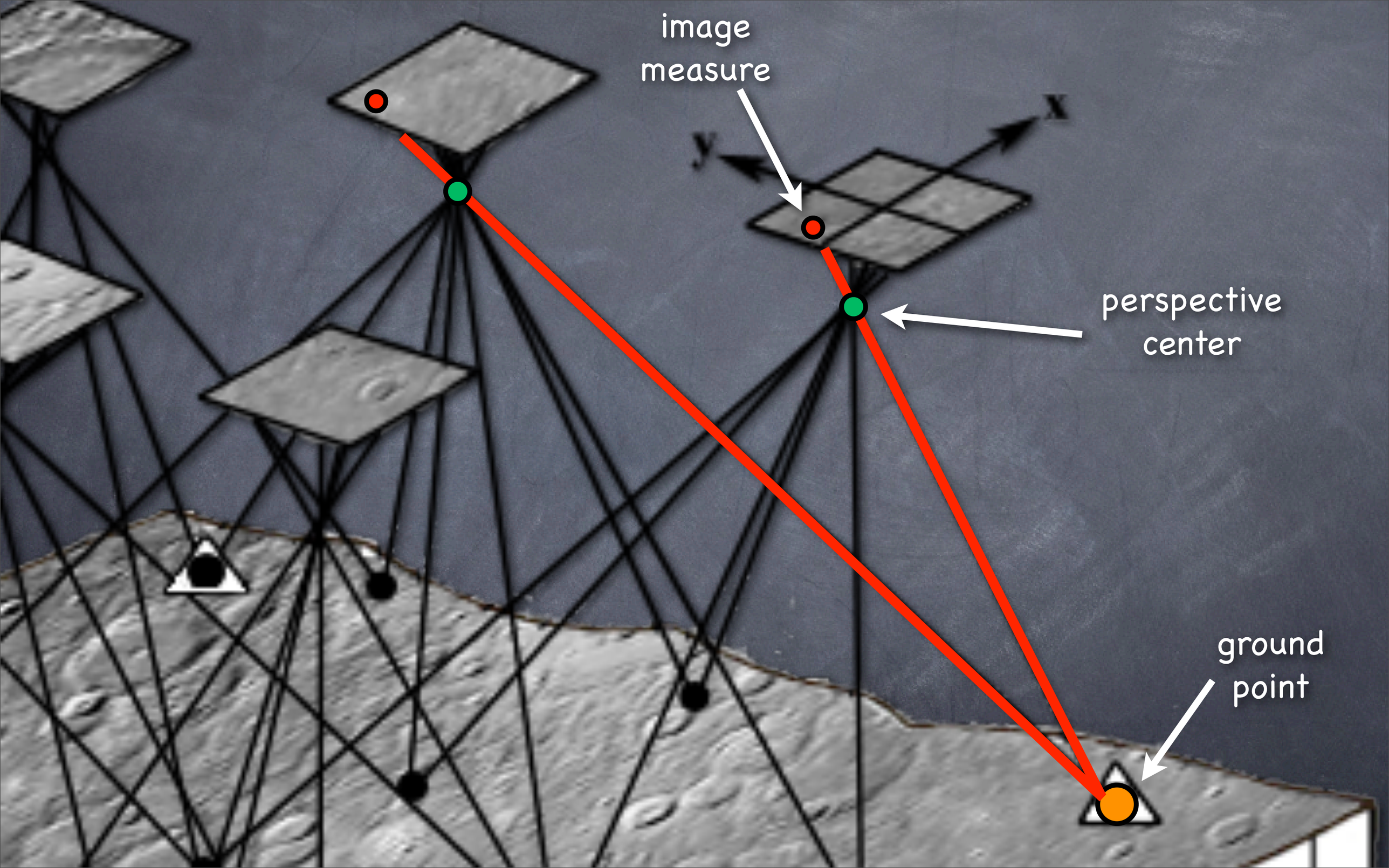
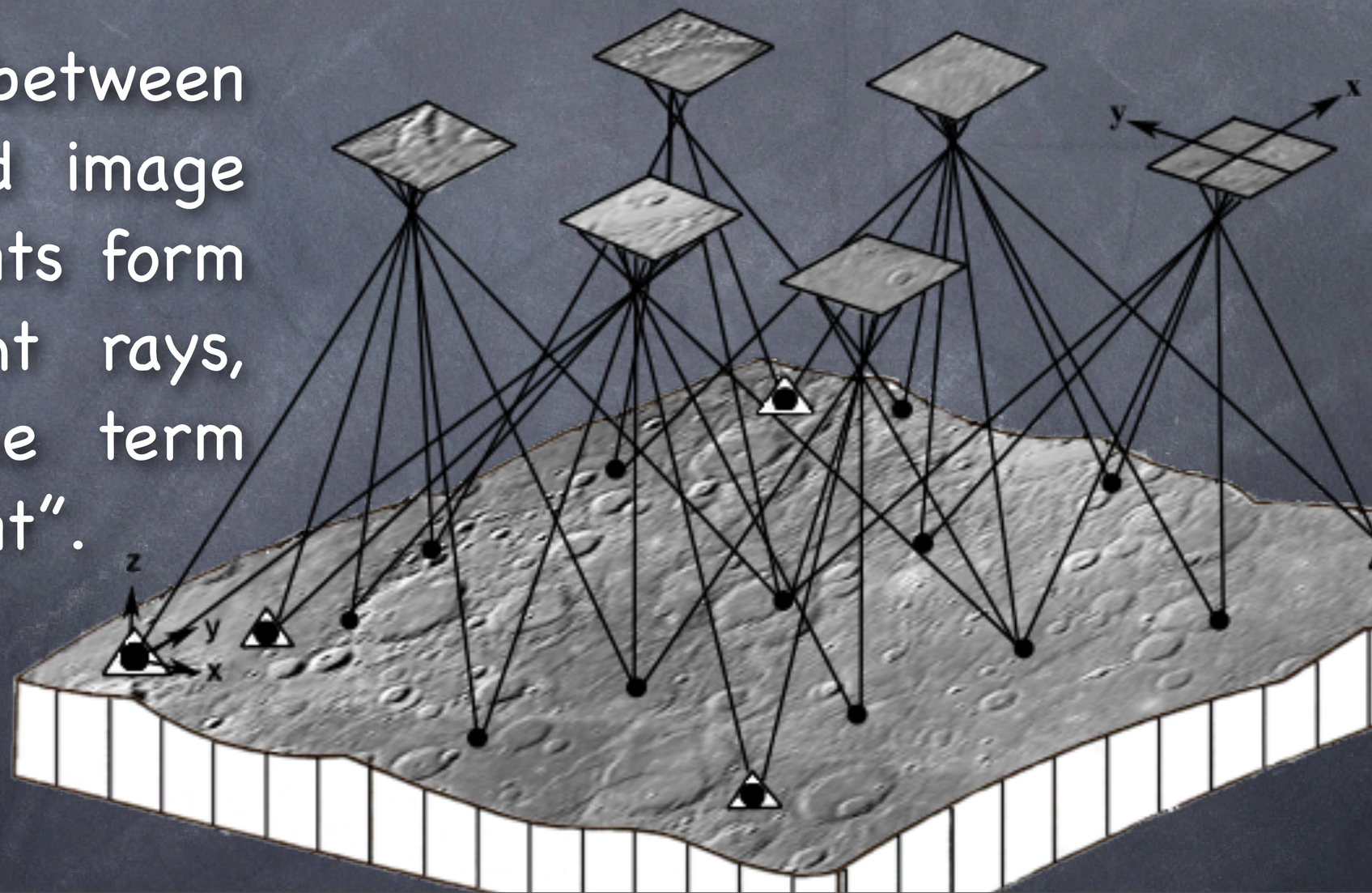


image
measure
y
x
perspective
center
ground
point

The Bundle Adjustment

All connections between object points and image space measurements form a bundle of light rays, the origin of the term "Bundle Adjustment".



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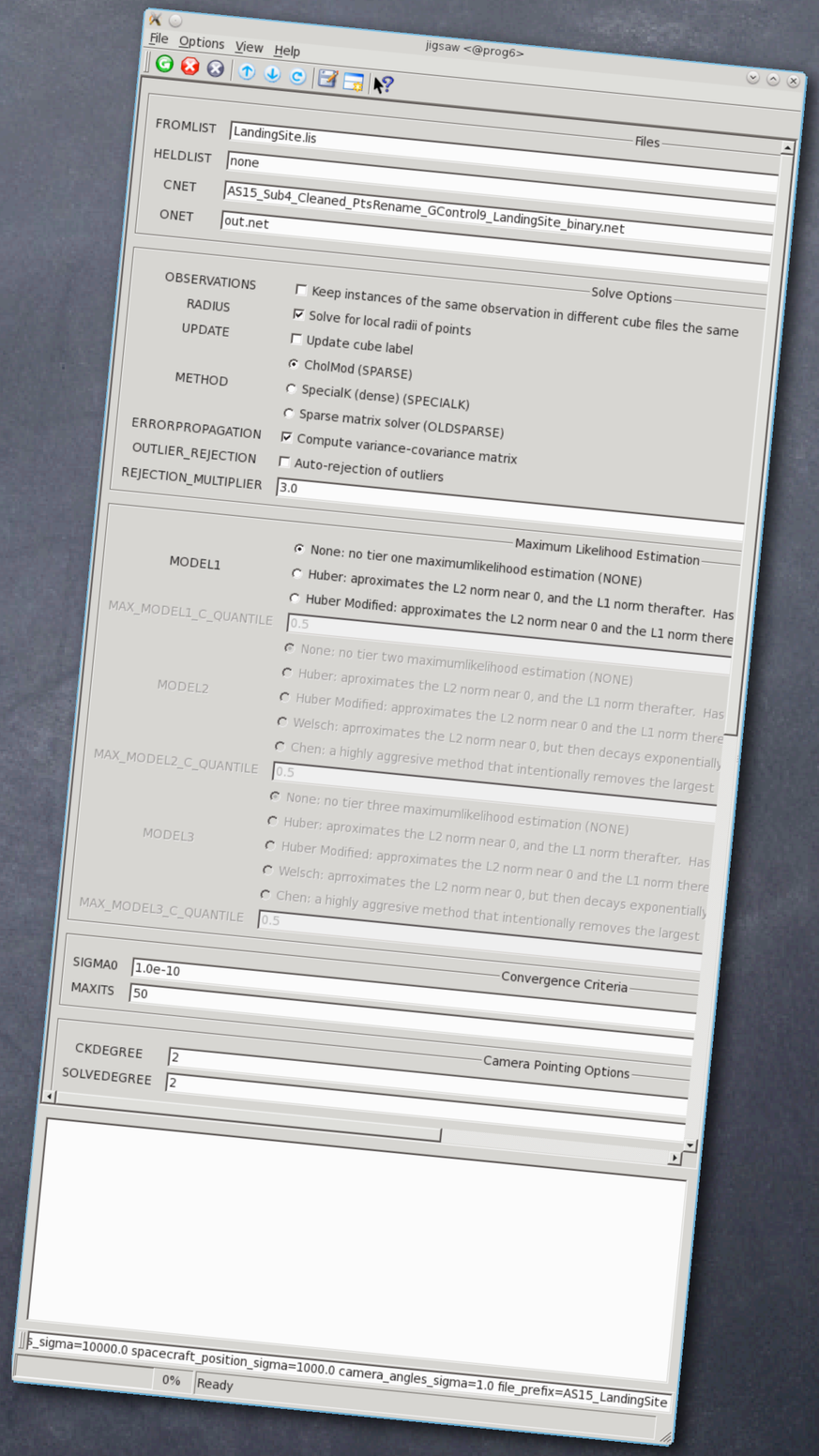
Jigsaw Interface



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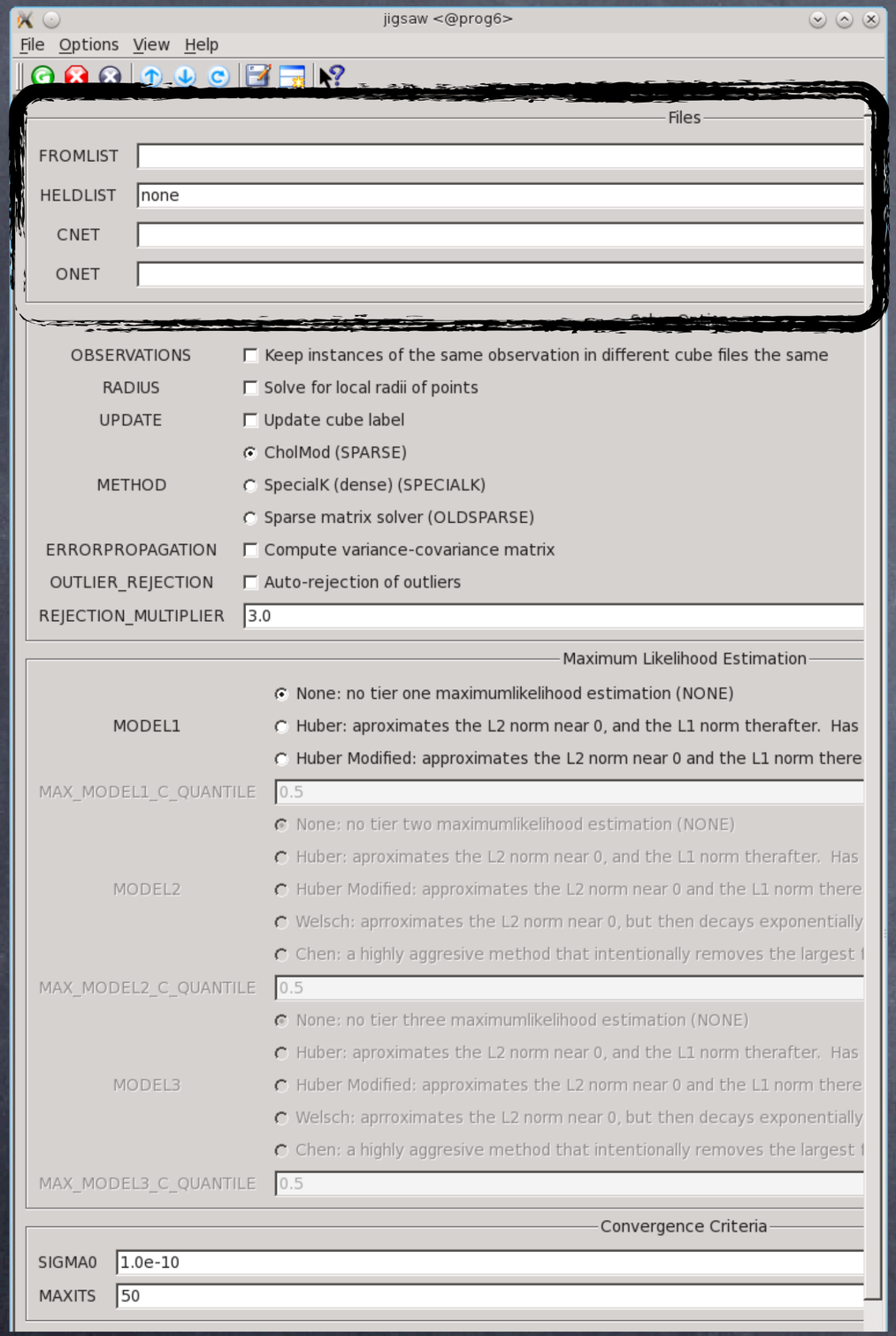

Files

- FROMLIST
  - ascii list of images in the control network.
- HELDLIST
  - ascii list of images for which position & pointing parameters are to be held fixed.
- CNET
  - Input control network.
- ONET
  - Output control network.

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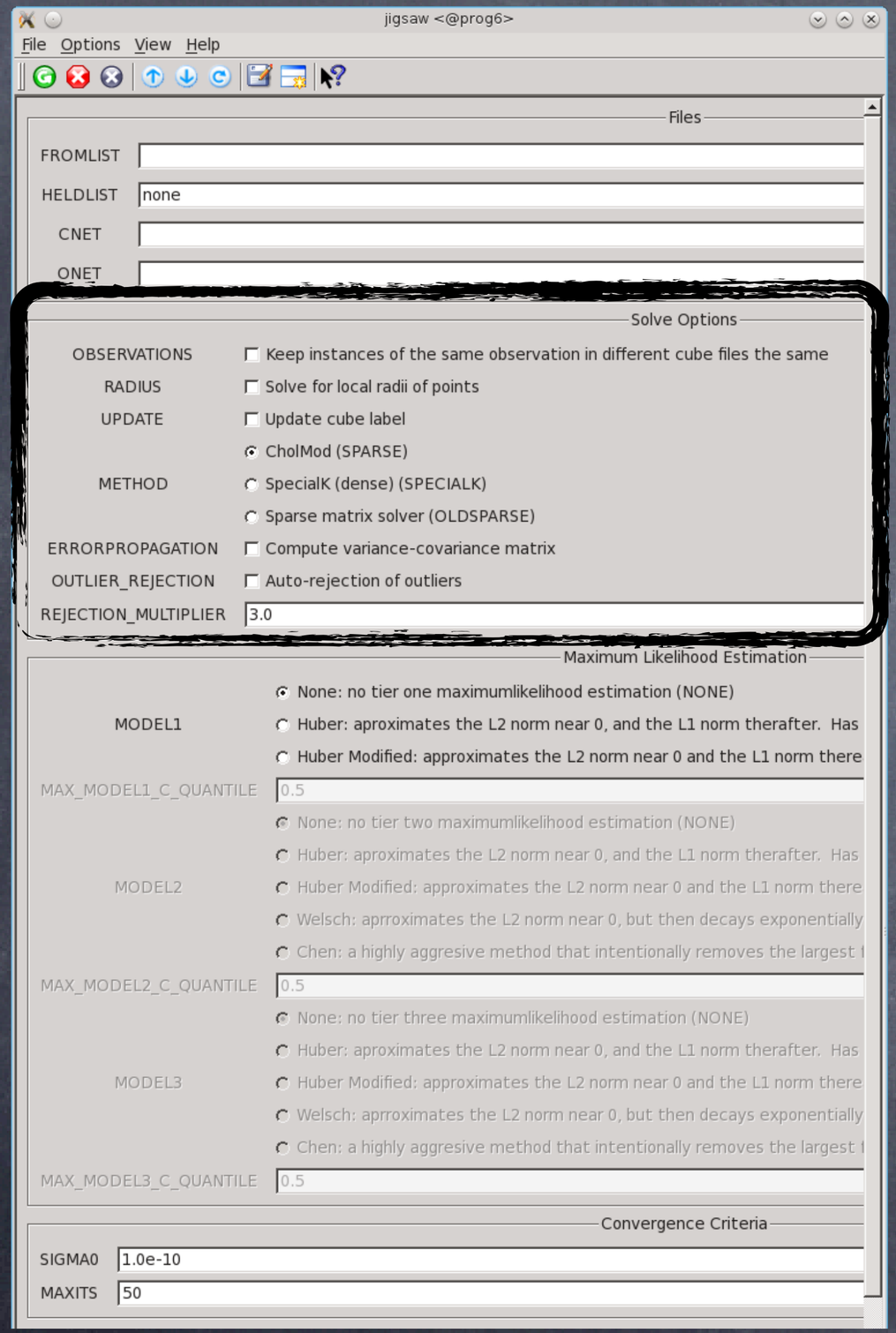

Solve Options

- OBSERVATIONS (Observation Mode)
  - All images within an "observation" have the same position & pointing.
  - Example: LRO NAC L/R
- RADIUS
- UPDATE
- METHOD
  - CholMod (default)
  - SpecialK
  - OLDSPARSE

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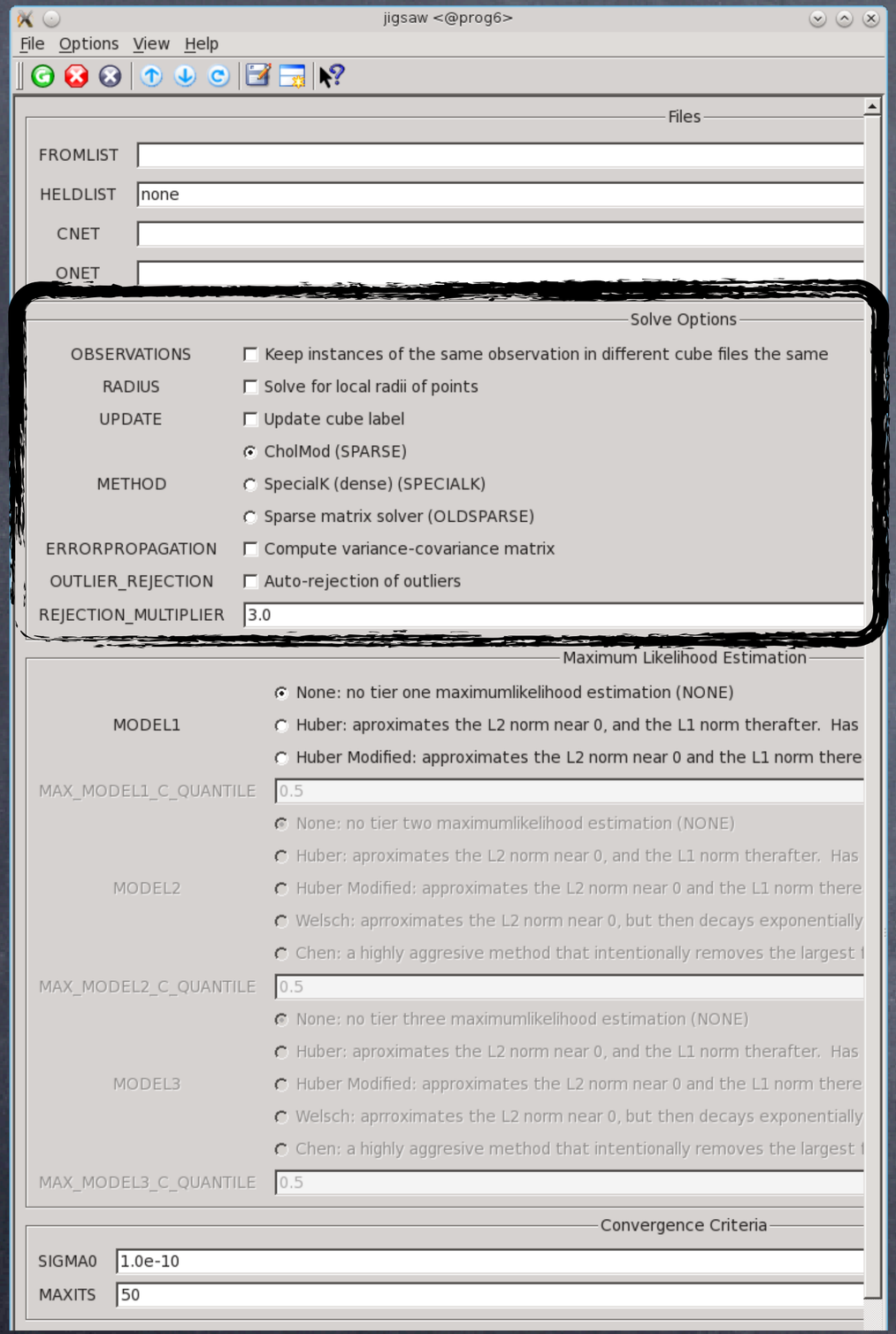
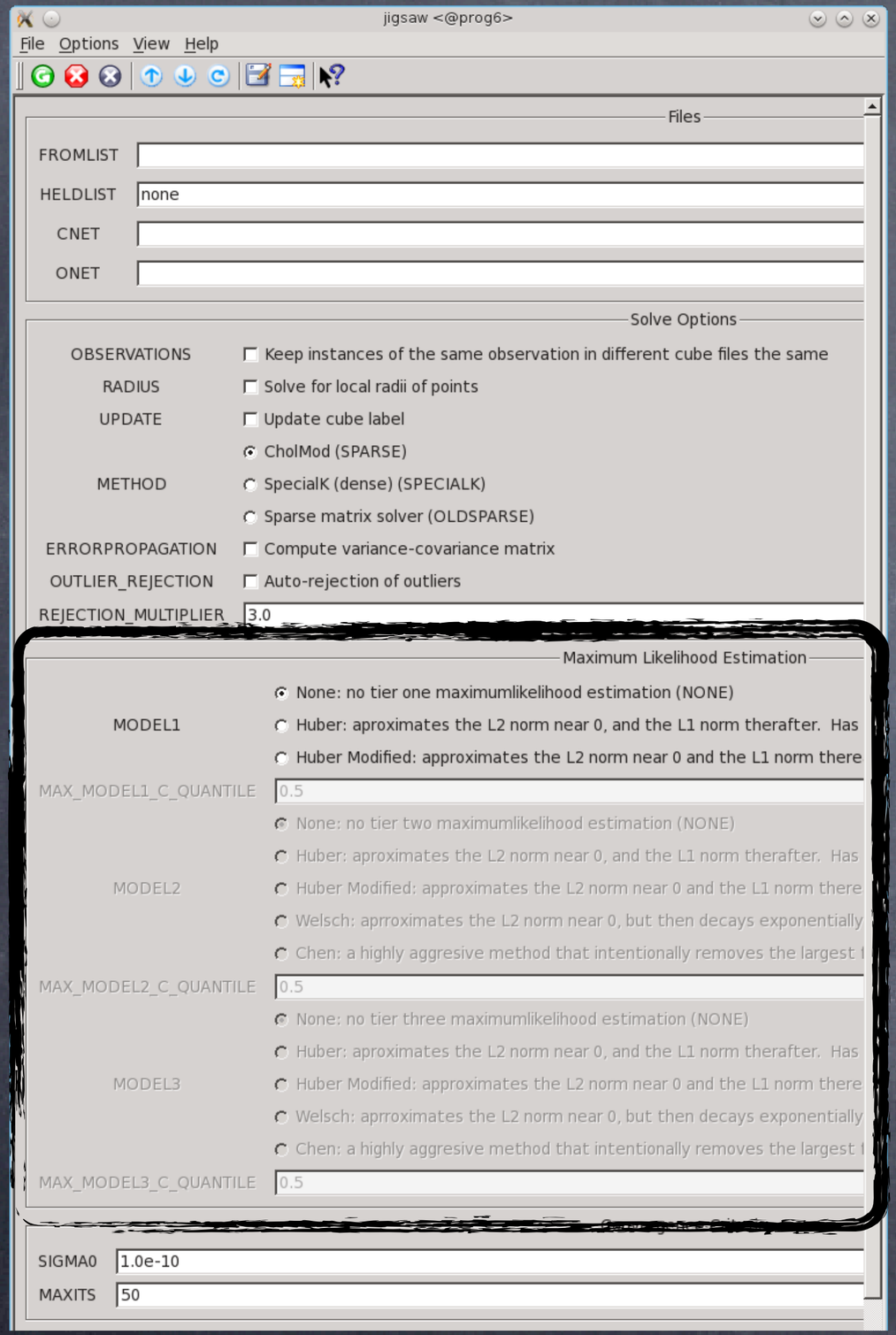


Solve Options

- ERRORPROPAGATION
  - Generation of parameter uncertainties.
- OUTLIER REJECTION
  - Automated rejection of outliers
- REJECTION_MULTIPLIER
- METHOD
  - CholMod (default)
  - SpecialK
  - OLDSPARSE

Maximum Likelihood Estimation



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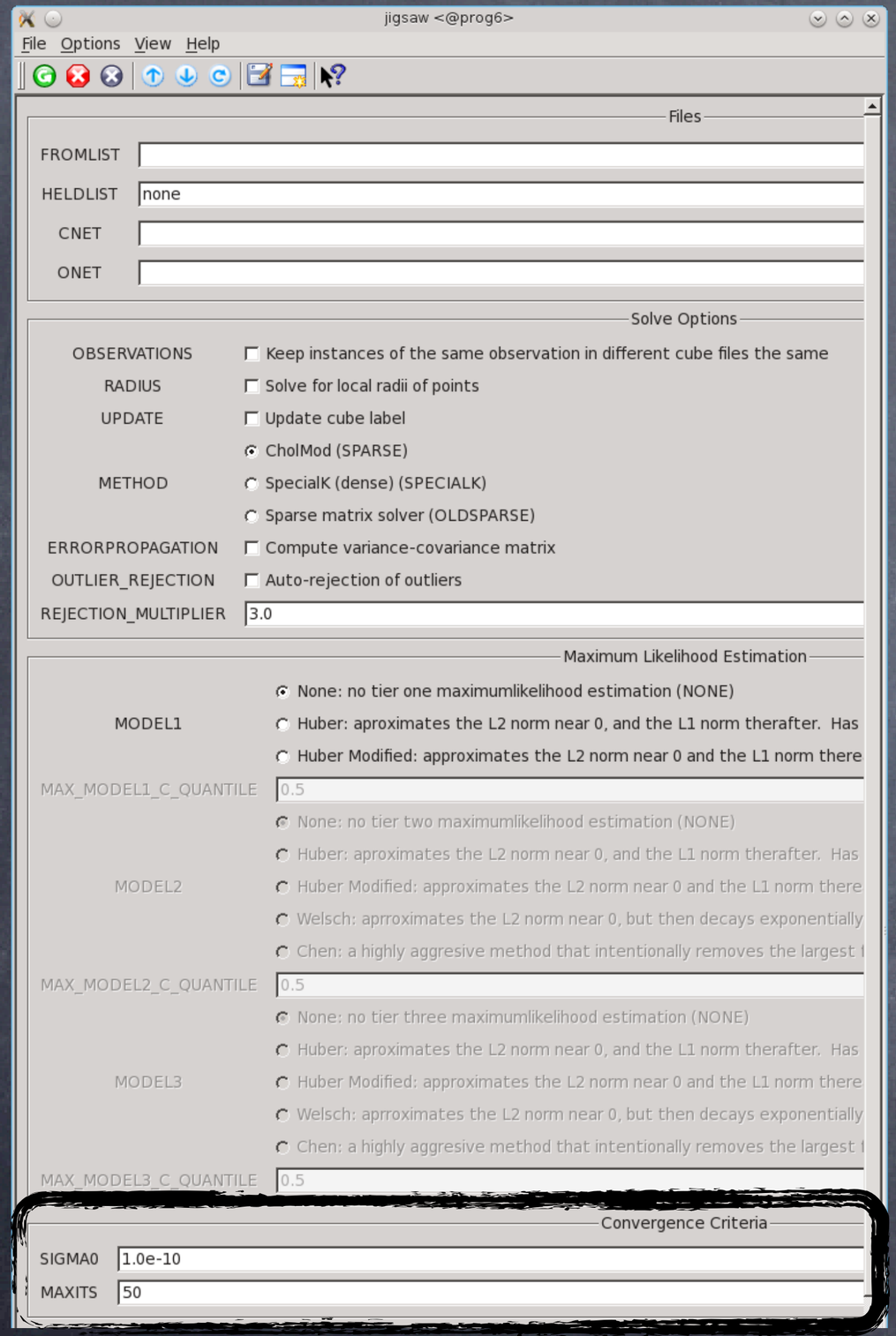

Convergence Criteria

- SIGMA0
  - Convergence occurs when change in Sigma0 in successive iterations is less or equal to this value.
  - Setting to a larger value results in fewer iterations.
- MAXITS
  - Adjustment stops (regardless of convergence) upon reaching maximum iterations.

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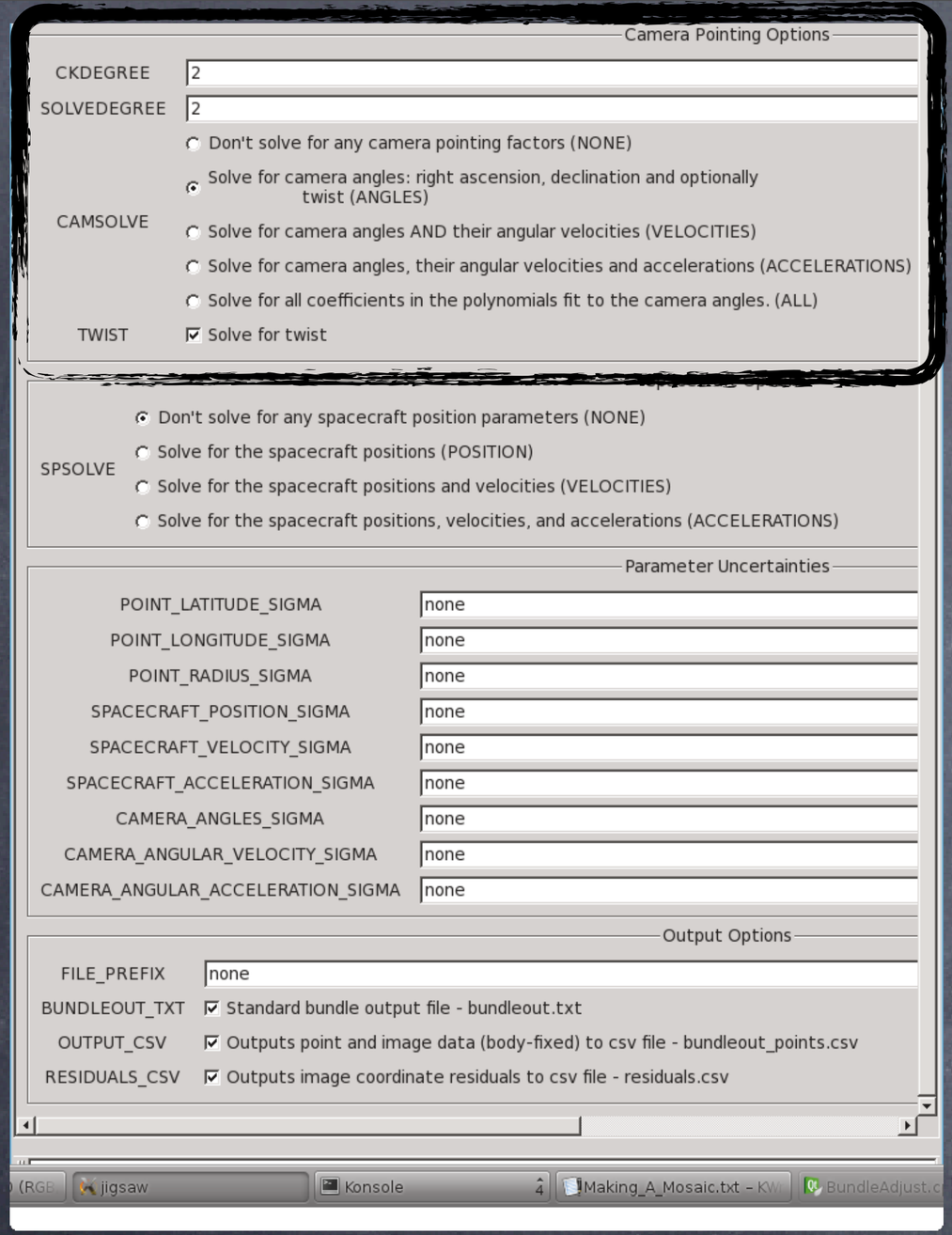
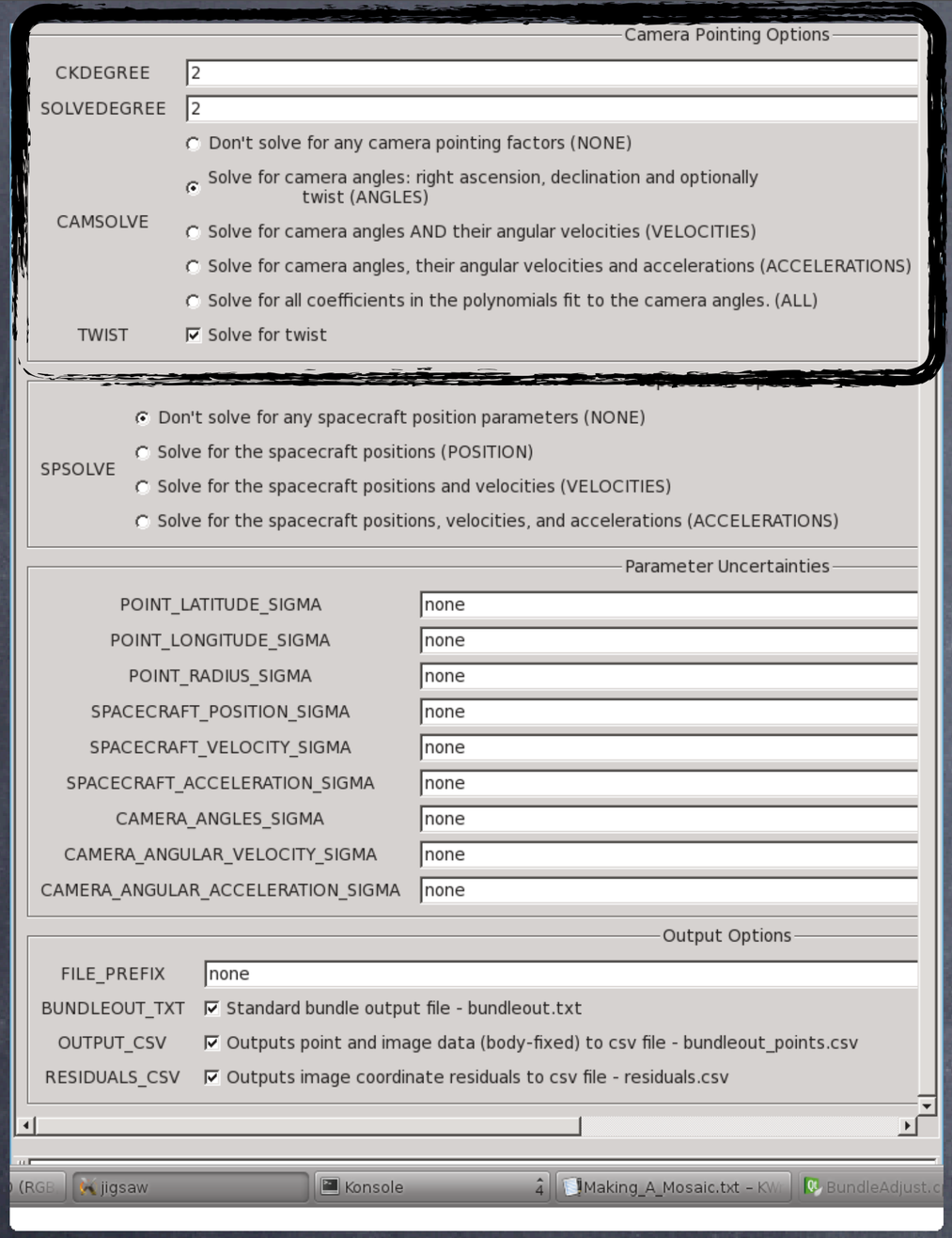
Camera Pointing Options

- CKDEGREE
  - Degree of polynomial for computation of initial values (time-dependent sensors, e.g. line scan).



Camera Pointing Options



- SOLVEDEGREE
  - Degree of polynomial in adjustment.
- e.g., degree of 2 ⇒ solving for 3 polynomial coefficients.
- $at^2 + bt + c$; where
  - t = time
  - a = angular acceleration
  - b = angular velocity
  - c = angle

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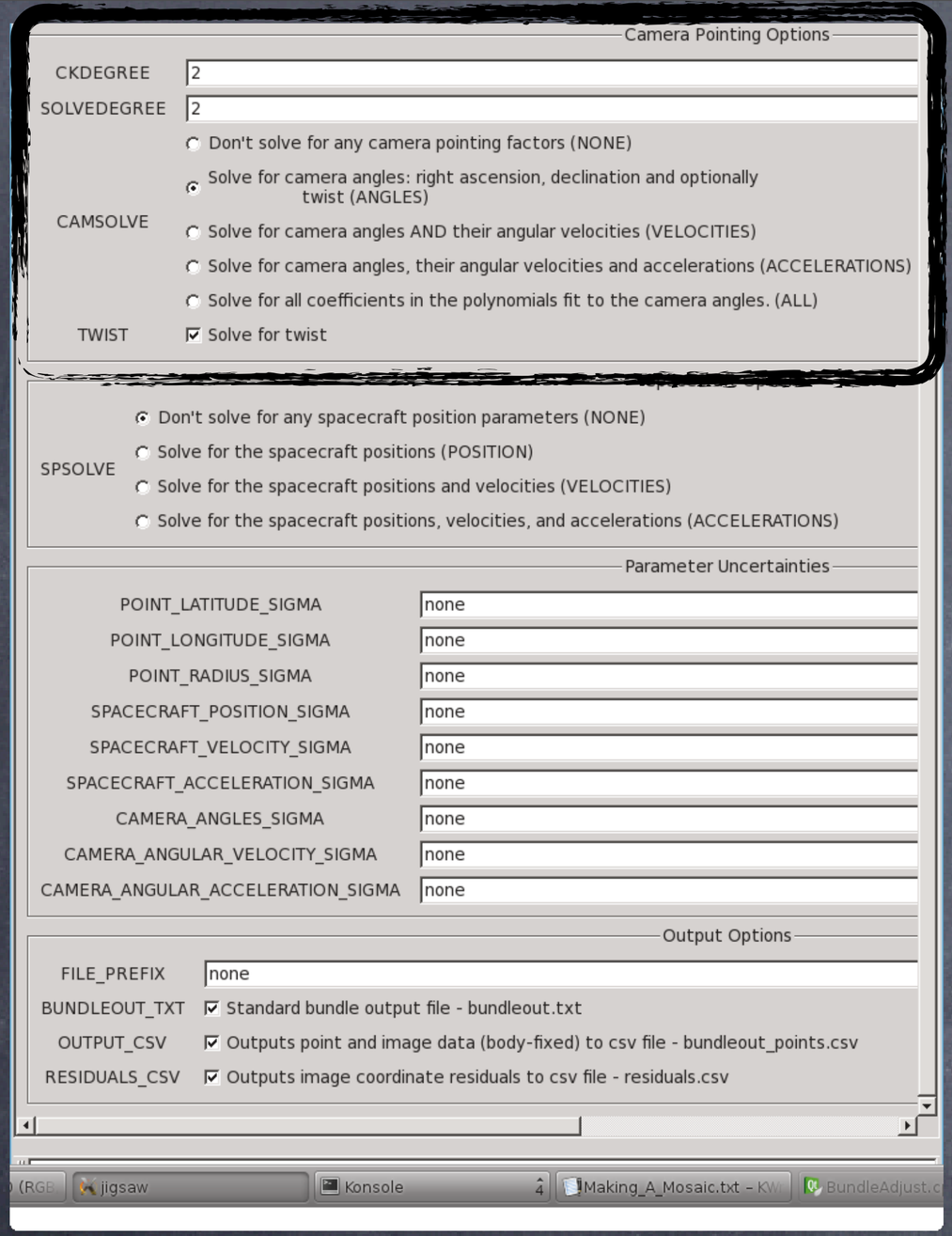
Camera Pointing Options



- CAMSOLVE
  - Selection of angular parameters in the adjustment.
- TWIST

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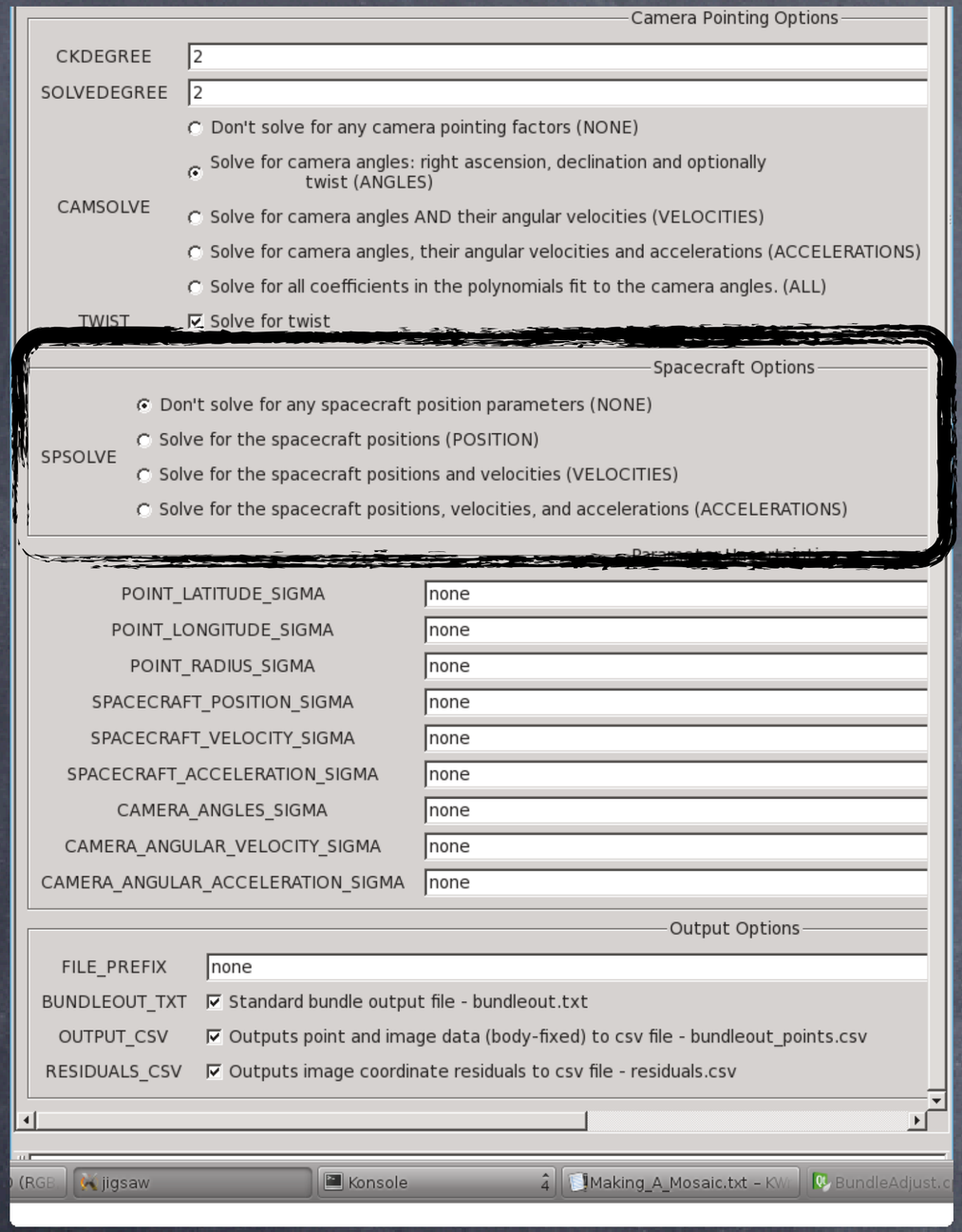
Spacecraft Options



- SPSOLVE
  - Selection of spacecraft position parameters in the adjustment.
- NOTE: capability to solve for coefficients of higher degree polynomials (as with pointing) is coming soon.

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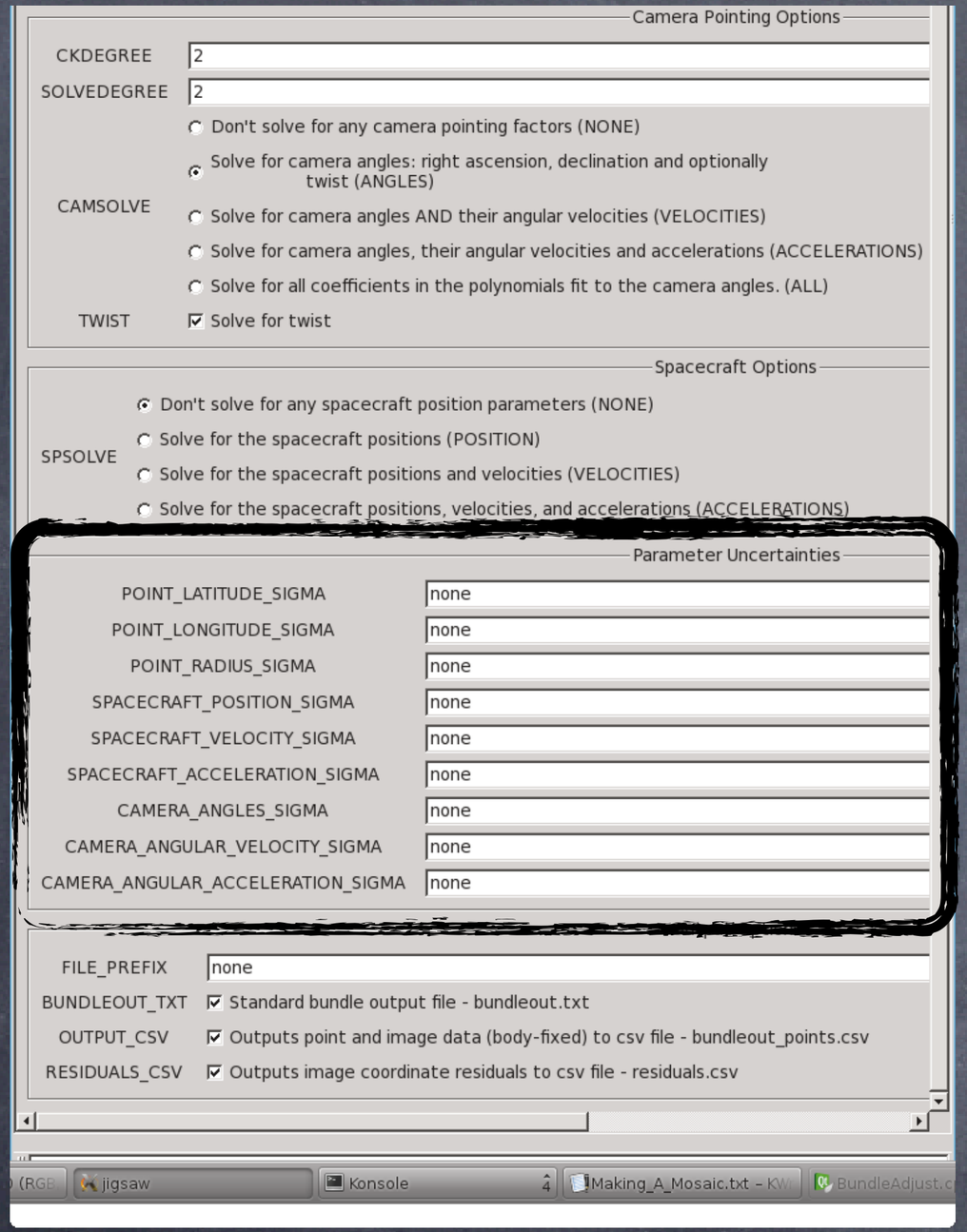
Global Parameter Uncertainties



- Global 'a priori' uncertainties for ground point coordinates, position, & pointing parameters.
  - Parameter weights in the adjustment are computed from uncertainties.
- Point sigmas in control network take precedence.

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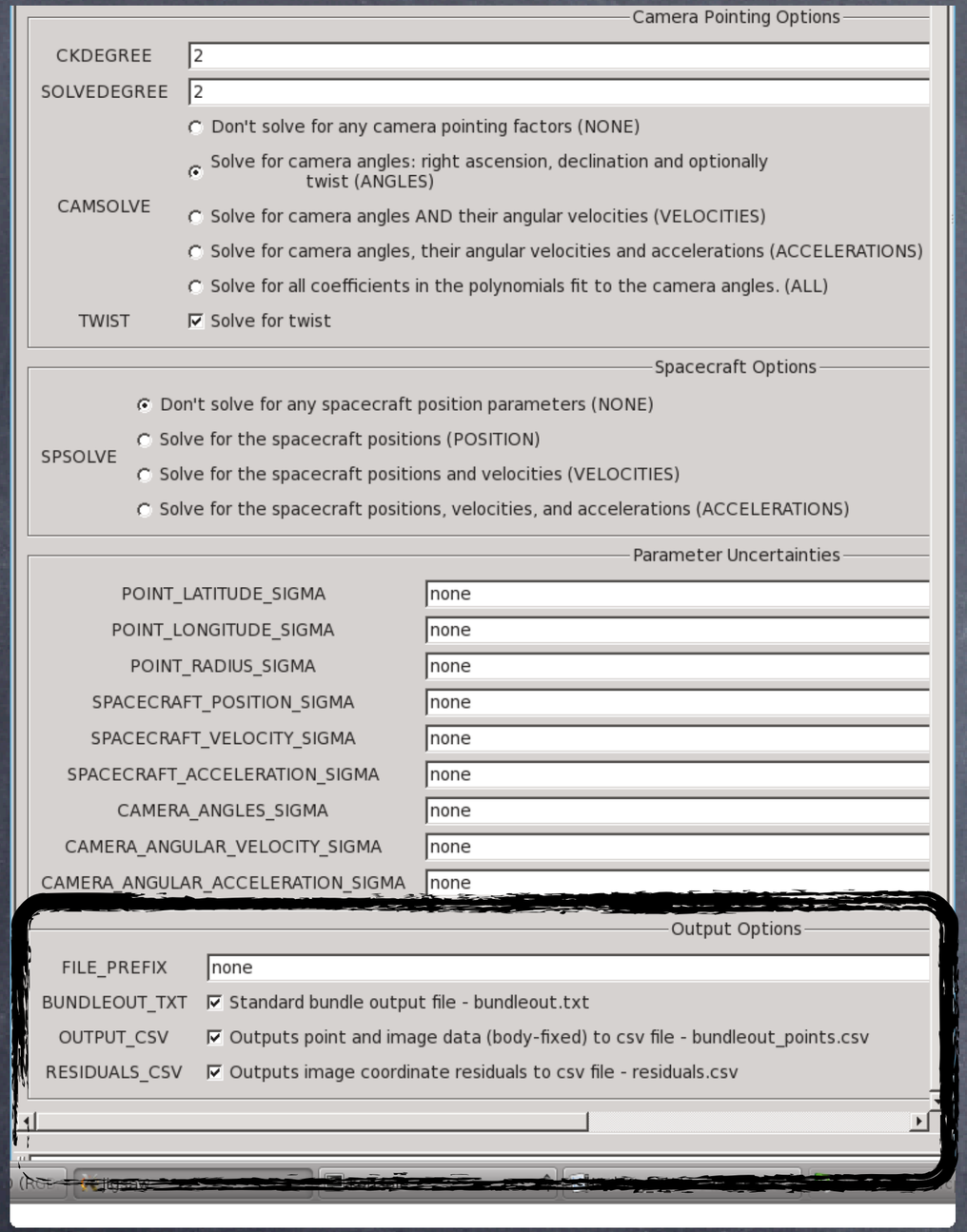

Output Options

- FILE_PREFIX
- BUNDLEOUT_TXT
  - Standard report "bundleout.txt" contains...
    - adjusted parameters
    - adjusted parameter uncertainties (if error propagation is on)
    - Statistics
- OUTPUT_CSV
  - "bundleout_images.csv"
  - "bundleout_points.csv"

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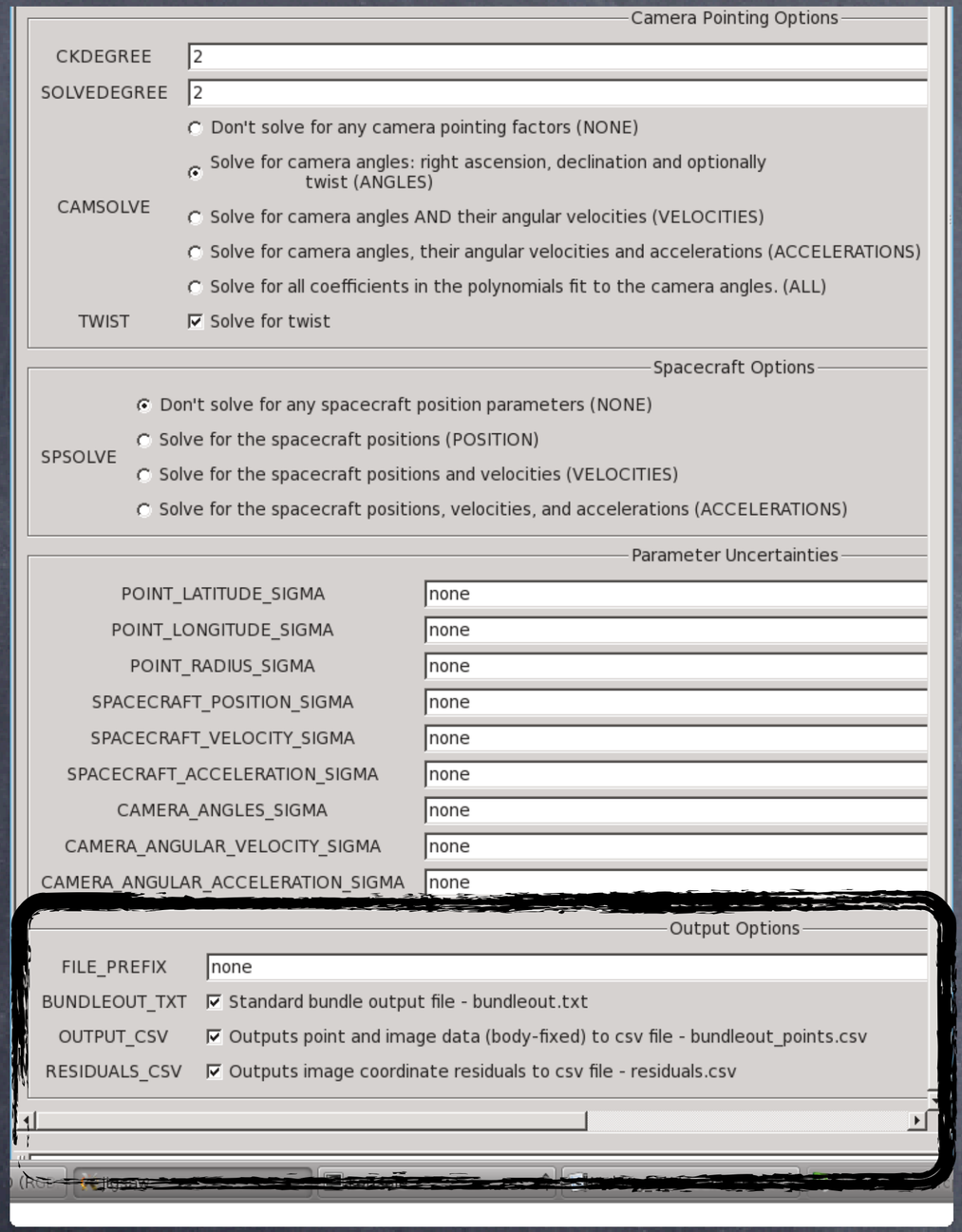

Output Options

- RESIDUALS_CSV
  - "residuals_images.csv"

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Output

```
                Run Time: 2012-06-22T15:39:42
      Network Filename: AS15_Sub4_Cleaned_PtsRename_GControl9_LandingSite_binary.net
              Network Id: LandingSite
  Network Description: cnetextracted
                  Target: Moon

             Linear Units: kilometers
           Angular Units: decimal degrees
INPUT: SOLVE OPTIONS
=====================

                OBSERVATIONS: OFF
                      RADIUS: ON
           SOLUTION TYPE: SPARSE
     ERROR PROPAGATION: ON
      OUTLIER REJECTION: ON
  REJECTION MULTIPLIER: 3.000000
MAXIMUM LIKELIHOOD ESTIMATION
=============================

          Tier 0 Enabled: FALSE
          Tier 1 Enabled: FALSE
          Tier 2 Enabled: FALSE
INPUT: CONVERGENCE CRITERIA
===========================

                    SIGMA0: 1.000000e-10
  MAXIMUM ITERATIONS: 50
INPUT: CAMERA POINTING OPTIONS
==============================

               CAMSOLVE: ANGLES
                  TWIST: ON
INPUT: SPACECRAFT OPTIONS
=========================

               SPSOLVE: POSITION
INPUT: GLOBAL IMAGE PARAMETER UNCERTAINTIES
===========================================

       POINT LATITUDE SIGMA: N/A
      POINT LONGITUDE SIGMA: N/A
          POINT RADIUS SIGMA: N/A
  SPACECRAFT POSITION SIGMA: 500.000000 (meters)
  SPACECRAFT VELOCITY SIGMA: N/A
SPACECRAFT ACCELERATION SIGMA: N/A
         CAMERA ANGLES SIGMA: 3.000000 (dd)
CAMERA ANGULAR VELOCITY SIGMA: N/A
CAMERA ANGULAR ACCELERATION SIGMA: N/A

JIGSAW: RESULTS
===============

                      Images:      5
                      Points:    395
              Total Measures:    950
        Total Observations:   1900
        Good Observations:   1844
    Rejected Observations:     56
Constrained Point Parameters:     99
Constrained Image Parameters:     30
                  Unknowns:   1215
      Degrees of Freedom:    758
    Convergence Criteria:  1e-10(Sigma0)
                  Iterations:      6
                      Sigma0:          0.55322850893198283195
Error Propagation Elapsed Time: 0.0500 (seconds)
    Total Elapsed Time: 0.4400 (seconds)

        Residual Percentiles:
            Percentile   1:   -1.486
            Percentile   2:   -1.118
            Percentile   3:   -0.868
            Percentile   4:   -0.756
            Percentile   5:   -0.658
            Percentile   6:   -0.602
            Percentile   7:   -0.545
            Percentile   8:   -0.498
            Percentile   9:   -0.468
                                                Percentile  34:   -0.014
                                                Percentile  35:   -0.010
                                                Percentile  36:   -0.008
                                                Percentile  37:   -0.006
                                                Percentile  38:   -0.004
                                                Percentile  39:   -0.003
                                                Percentile  40:   -0.003
                                                                                Percent
                                                                                Percent
                                                                                Percent
                                                                                Percent
                                                                                Percent
                                                                                Percent
```

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Examining the Results

Things to look for...

- Sigma0: ideally close to 1.0.
- Examine measure residuals for outliers.
- Unreasonably high adjusted parameter uncertainties.
- Magnitude of the corrections to weighted parameters.

Potential problems to consider...

- Poor a priori parameter values - Bad SPICE? Problem DEM?
- Measurement errors - Wrong feature? Wrong point label?
- Improperly weighted point coordinates?
- Weak image geometry?
- Number and geometry of image measurements for a ground point
- Camera model problem?

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