3D reconstruction of small bodies from in-situ visible images

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3D RECONSTRUCTION METHODS

Classes of disk-resolved reconstruction techniques:

● Shape-from-silhouette	uses limb profiles
● Stereo	uses pixel values
● Shape-from-shading	uses pixel values

Many “flavors” of these techniques are available ...

3D RECONSTRUCTION METHODS

3D reconstruction methods for Steins & Lutetia:

- **Method 1 → Limb profiles** (O. Groussin)
- **Method 2 → Spherical Harmonics** (L. Jorda, S. Spjuth)
- **Method 3 → Stereo – Control points** (S. Besse)
- **Method 4 → Shape deformation** (G. Gesquière)
- **Method 5 → Stereophotoclinometry** (R. Gaskell)
- **Method 6 → Refined photoclinometry** (L. Jorda, C. Capanna, S. Spjuth)

Further combined with LCs inversion technique (M. Kaasalainen)

By-products:

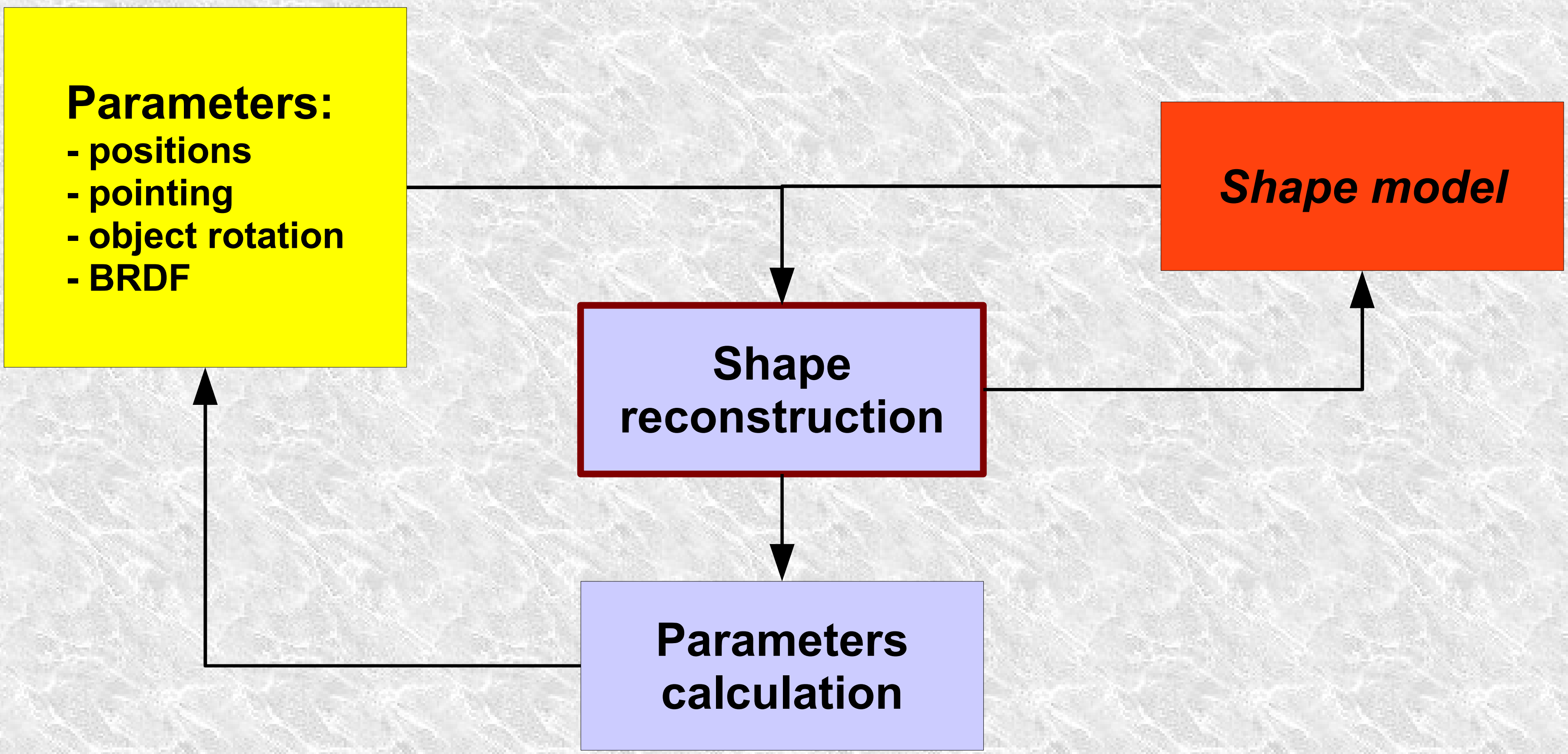
→ **Camera pointing (+ S/C-object vector)**

→ **Direction of the spin axis (+ period)**

→ **Physical parameters (CoM, PAIs, BRDF, etc.)**

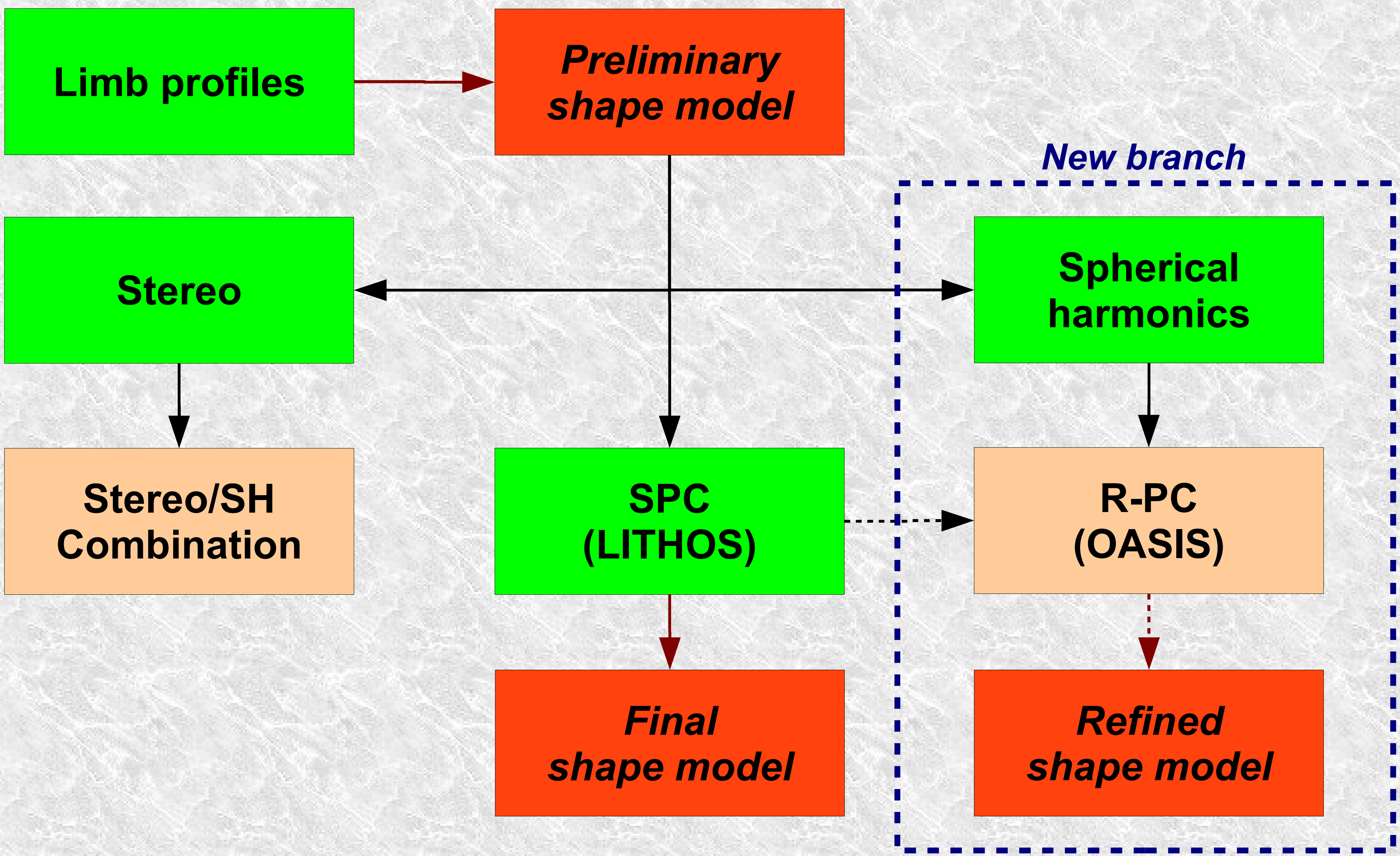
3D RECONSTRUCTION METHODS

Calculation of additional parameters



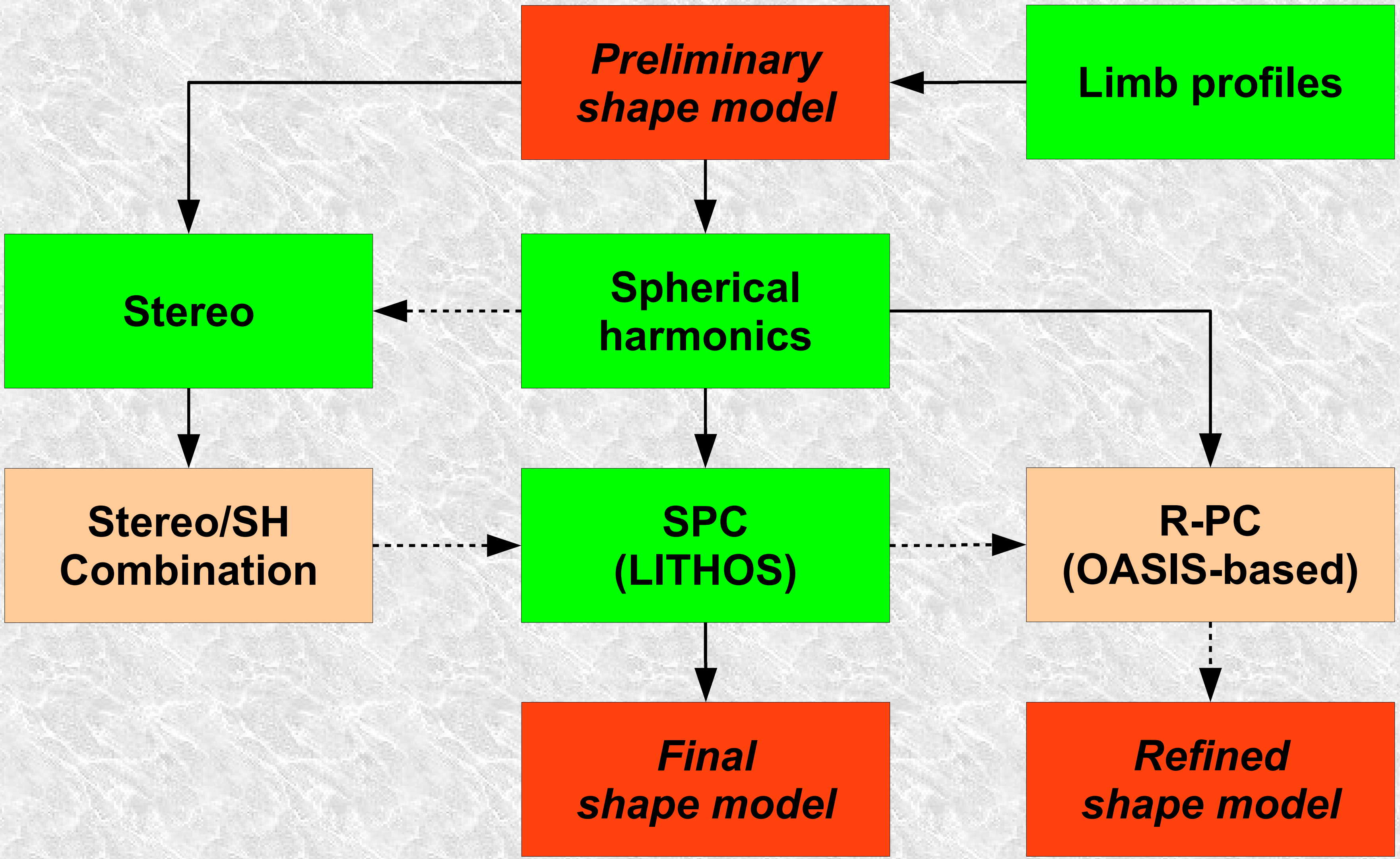
3D RECONSTRUCTION METHODS

Pipeline used for the analysis of 2867 Steins



3D RECONSTRUCTION METHODS

Pipeline foreseen for the analysis of 21 Lutetia



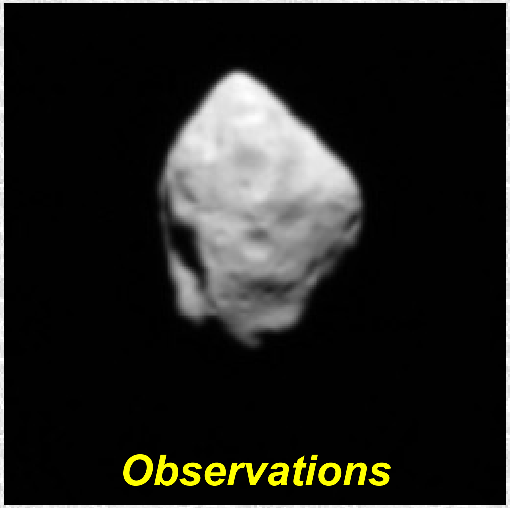
DESCRIPTION OF THE METHODS

Limb profiles

Steps:

Tool calling OpenGL written in C

1. Determination of rough pointing directions
2. Interactive determination of:
   - the pointing direction
   - the shape by erosion from limb profiles
3. Iteration of the method
4. Manual addition of craters (optional)



Observations

Limb profile+craters

DESCRIPTION OF THE METHODS

Limb profiles

Pros:

- **Very fast (little CPU required)**
- **Easy to operate**
- **Little apriori information required !**
- **Can use also low resolution images**

Cons:

- **Operator-dependent**
- **Few constraints between limb profiles: no “topography”**
- **No constraints near the terminator**
- **Concavities not always captured in the final model**

→ ***Very important starting point***

DESCRIPTION OF THE METHODS

Spherical Harmonics

Steps:

Tool in F95 calling LBFGS+SHTOOLS*

1. Determination of additional parameters

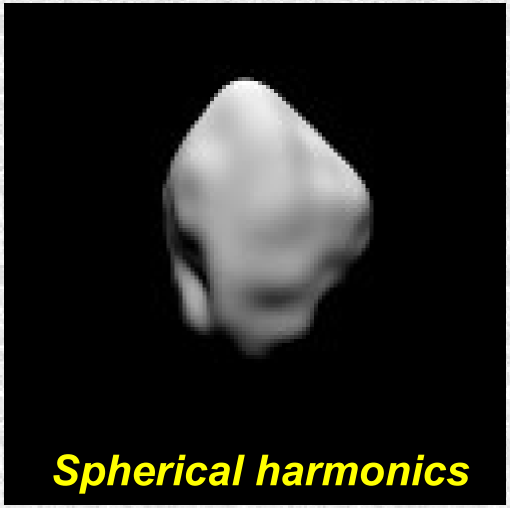
- pointing, rotation, etc...

2. Direct optimization of the SH coefficients

- shape described as a SH development

3. Iteration of the method

Observations



Spherical harmonics

****parallelized with OpenMP***

DESCRIPTION OF THE METHODS

Spherical Harmonics

Pros:

- **Automatic**
- **Multi-resolution approach**
- **Can use also low resolution images**
- **Terminators well reproduced**
- **Concavities also reproduced**

Cons:

- **Requires apriori knowledge of the BRDF**
- **Can become very consuming in CPU time**
- **Smooth model: no “topography”**

→ ***Good low resolution (smooth) shape model***

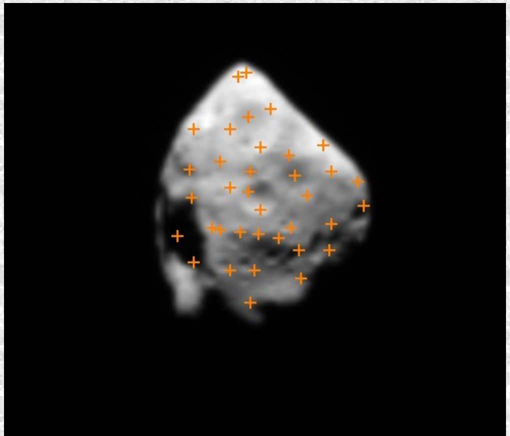
DESCRIPTION OF THE METHODS

Stereo

Steps:

Tool written in IDL

1. Determination of points of interest
   - "Fast Corner Detection" algorithm
2. Matching of these points
   - requires "geo-localization" (slow !)
3. Coordinates of GCPs in body-fixed frame
4. Iteration of the method
5. Creation of triangular mesh from the GCPs
   - Delaunay triangulation



Stereo (GCPs)

DESCRIPTION OF THE METHODS

Stereo

Pros:

- Automatic
- Purely geometric
- High accuracy at the GCPs
- Determination of large-scale topography

Cons:

- Requires high-resolution images
- No constraints between the GCPs
- CPU time on big models in current implementation ?

→ ***Improvement of shape models + geometric constraints***

DESCRIPTION OF THE METHODS

Shape deformation

Steps:

Tool written in C++

Uses simplex mesh representation of shape models

Method based on forces: $F_{tot} = F_{internal} + F_{external}$

- **Displacement constraints to localize the surfaces on POI** ($F_{external}$)
- **Avoid inappropriate deformations: internal force compensation** ($F_{internal}$)

Iterative process. Multiresolution approach (split cells).

Reference: **H. Delingette,**

« *General Object Reconstruction based on Simplex Meshes* »,

International Journal of Computer Vision, 32(2):111-146, 1999

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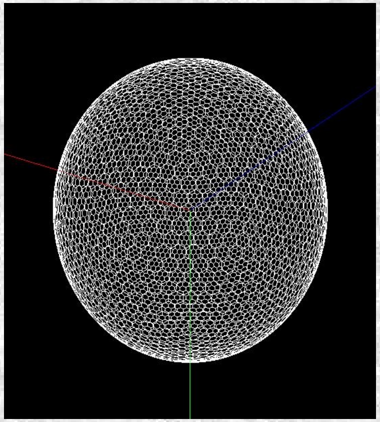
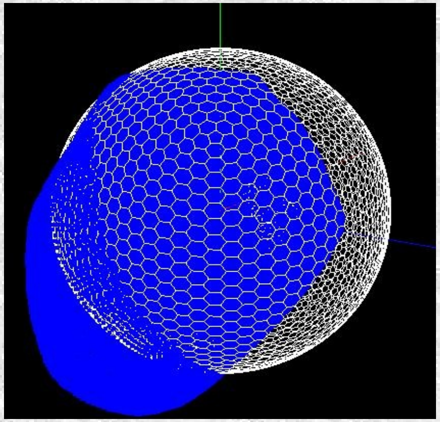
DESCRIPTION OF THE METHODS

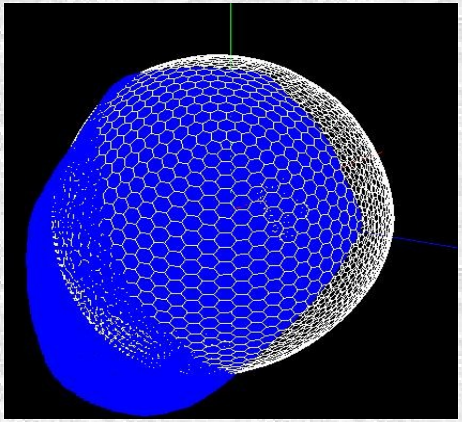
Shape deformation



Initial Shape

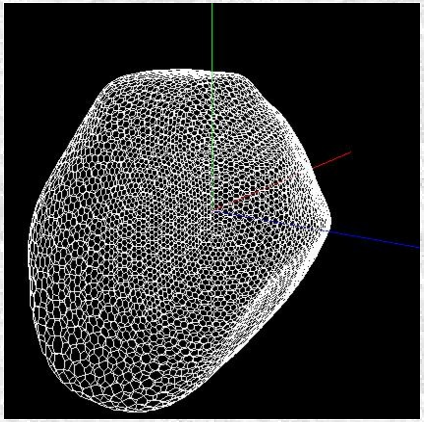


Initial Shape + POI



Deformation process

...



Deformed mesh

Mesh

POI

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DESCRIPTION OF THE METHODS

Stereophotoclinometry

Steps:

Tool LITHOS using SPICELIB written in F77

1. Choice of a set of “maplets”

2. Co-registration of maplets on several images

3. Calculation of additional parameters by stereo

- pointing, rotation, etc...

4. Determination of maplets local topography

5. Iteration of the method

6. Combination of maplets into a shape model

DESCRIPTION OF THE METHODS

Stereophotoclinometry

Pros:

- Combination of several techniques (stereo + PC + limb)
- Multi-resolution possible
- Intermediate results can be checked
- No apriori knowledge of BRDF
- Determination of low-scale topography
- High accuracy
- Very robust and well-tested !

DESCRIPTION OF THE METHODS

Stereophotoclinometry

Cons:

- Requires high-resolution images
- Operator-dependent (time consuming)
- Pbs: terminator + projected shadows + pixel-scale topography
- Limited to “simple” BRDF laws
- No output local error bars (...simply accessible...)
- No output “albedo map” (...simply accessible...)
- Documentation for “non-expert” users

→ ***well recognized “state of the art” method & program***

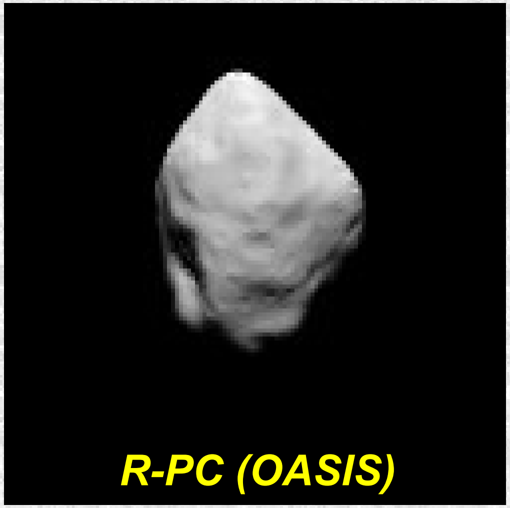
DESCRIPTION OF THE METHODS

"Refined photoclinometry"

Steps:

Tool in F95 using OASIS+CGMOD+LBFGS*

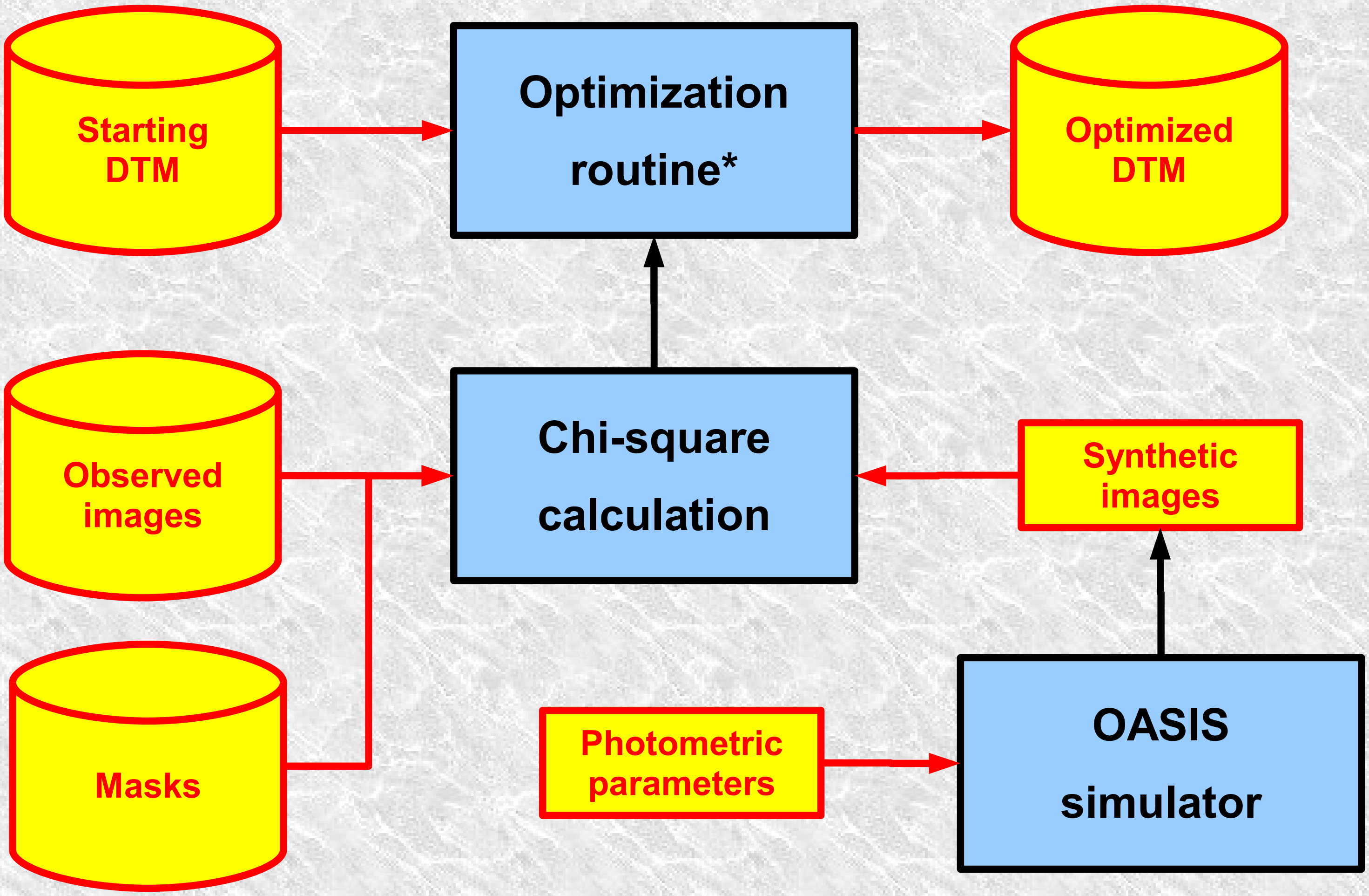
1. Selection of a DTM + associated images
2. Determination of the topography
   - direct optimization of the vertices (LBFGS)
   - comparison observed/synthetic images
3. Calculation of additional parameters
   - direct optimization (LBFGS)
   - BRDF, pointing, rotation, etc...
4. Iteration of the method
5. Combinations of the DTMs



****parallelized with OpenMP***

DESCRIPTION OF THE METHODS

"Refined photoclinometry"



DESCRIPTION OF THE METHODS

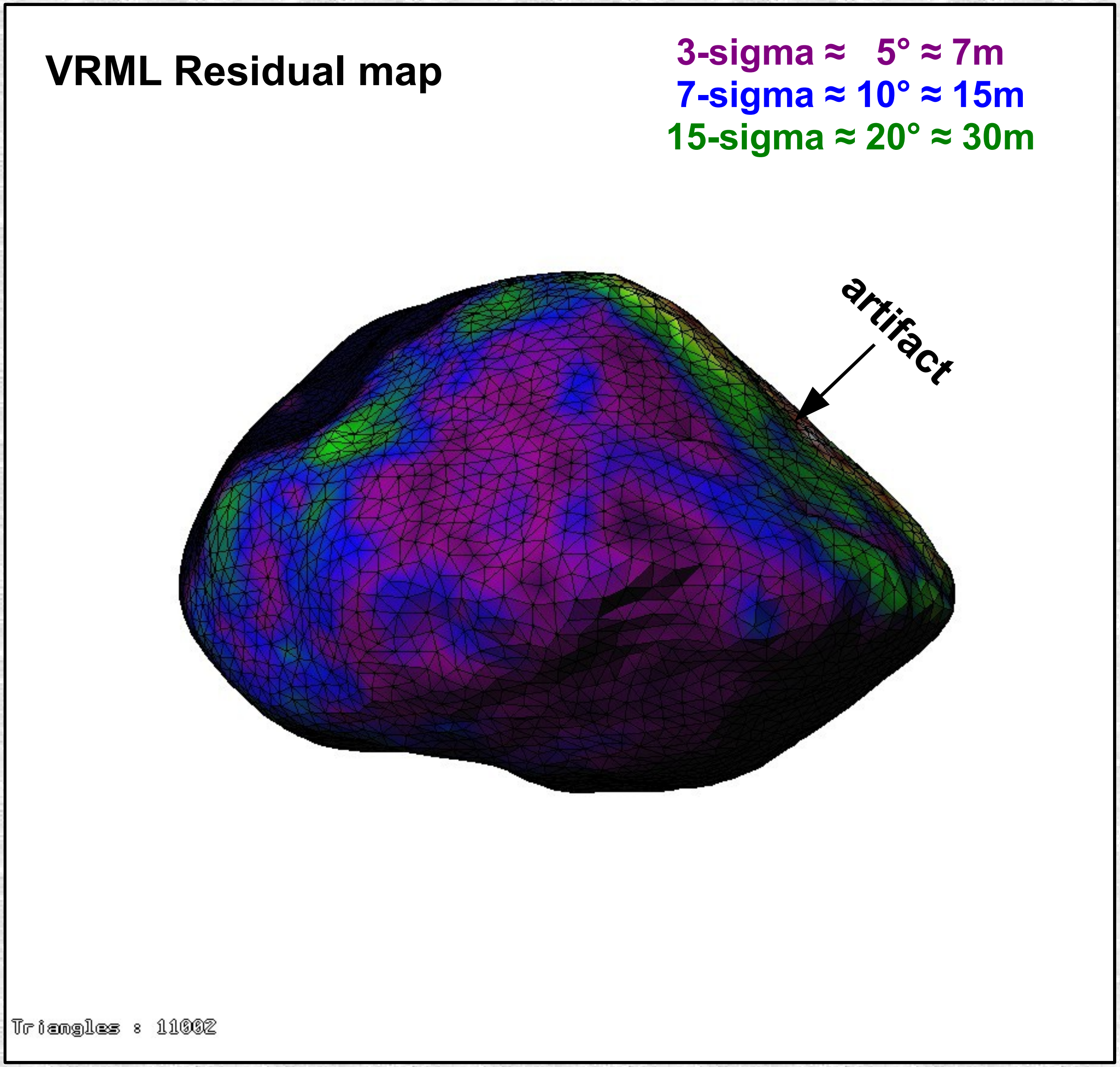
"Refined photoclinometry"

Pros:

- Very high accuracy
- Determination of low-scale topography
- Multi-resolution possible
- Can be easily automated = almost operator-independent
- Uses highly accurate BRDF laws (Hapke)
- Local topographic error map available
- Projected shadows/terminator regions fully included in fit
- Code fully "under control" and documented !

DESCRIPTION OF THE METHODS

"Refined photoclinometry"



DESCRIPTION OF THE METHODS

"Refined photoclinometry"

Cons:

- Requires high-resolution images
- Requires apriori knowledge of the BRDF
- Requires input shape model close to final solution
- Time consuming in preparation and CPU !
- Not well tested (except OASIS library)
- Not very robust: convergence not guaranteed

→ *final improvement of already accurate models*

FUTURE ACTIVITIES

Stereo:

- **Port the IDL code to C**
- **Finish up the shape deformation program**

Refined PC:

- **Further improvements of the code are ongoing (multi-resolution ...)**
- **More tests required (large models …)**

→ **Several papers submitted and in preparation**

→ **Our next activity: flyby of 21 Lutetia on July 10, 2010**

REQUIREMENTS AND PERFORMANCES

- **Number of targets:**

  - limited to the targets of space missions (~ 10 at the moment)

- **Requirements:**

  - from 1 to several 100 resolved images

  - photometric relative accuracy: < a few %

- **Combination with other techniques:**

  Additional techniques very useful to:

  - provide input rotational parameters

  - constrain the unobserved surface (as done for Steins)

  For the latter, the codes must be adapted to handle constraints coming from in-situ observations.

REQUIREMENTS AND PERFORMANCES

Accuracy depends on:

- Flyby distance → (x,y) accuracy
- DN level and number of images (photon noise) → z accuracy
- Viewing angles coverage of a given surface area → stereo

Expected accuracy:

- Limb method: ~1 pixel near limb profiles
- Stereo: ~1/8 pixel at the control points
- Photoclinometry: ~1/4 pixel in (x,y) *(assuming ~10 images/area)*
  ~1/10 pixel in z (local slopes ~5 deg)
- BRDF: ~ 1 % at pixel resolution (relative)

→ **Relative** camera pointing: ~1/10 pixel

PERSPECTIVES

Flyby of 21 Lutetia (NAC image)