Multi-Mission Laser Altimeter Processing and Co-Registration of Image and Laser Data at DLR

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Laser data used for analysis at DLR

Previous missions:

- MOLA on MGS
- NLR on NEAR
- LALT on Kaguya
- MLA on Messenger

Current mission:

- LOLA on LRO

Future missions (PI instruments from DLR):

- BELA on BepiColombo
- GALA on JUICE

Database

RedHat Enterprise 7.4

PostgreSQL 10.3

PostGIS extension 2.4.4

Some numbers:

595.0 Mio. MOLA shots
4.1 Mio. MLA shots
2190.0 Mio. LOLA shots

700 Mio. BELA shots (2 years of continuous operation)
510 Mio. GALA shots (132 days in final Ganymede orbit)

Analyzing existing Laser Data

Analyzing existing Laser Data

- **Laser data provides**:
  - Range from s/c to surface (*accuracy in the order of 1 m*)
  - Topography information (planetary radii) (*accuracy in the order of 10 m*)
  - Albedo of the surface at laser wavelength (*typically at 1064 nm*)
  - Surface slopes (from consecutive spots along profile) (*typical baselines of hundreds of meters*)
  - Surface roughness (within the laser spot area) (*typical spot diameter 5 to 100 m*)

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Slope and Roughness

- Roughness is interesting for landing site selection.

- Can be obtained by analyzing the reflected laser shots (i.e. the pulse width).

- Formalism based on Eq. 11 in *Neumann et al., 2003, JGR* (MOLA roughness)

- All necessary values are available in DB or are constants, only the surface slope needs to be calculated

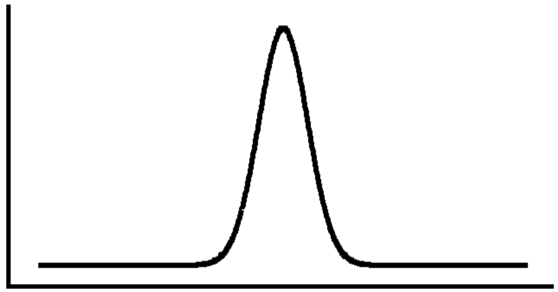
Slope and Roughness

Surface slope varies significantly with the selected baseline of the height measurements:

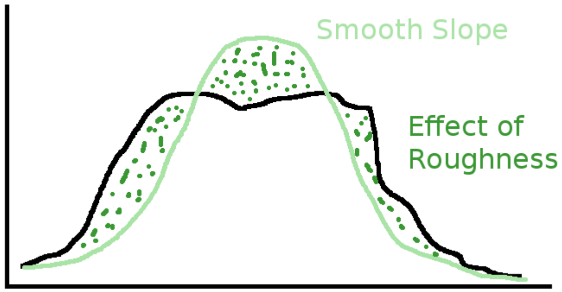
→ slope baseline can be tuned by user

→ both slope and roughness have to be calculated "on-the-fly"

Slope and Roughness



Outgoing Pulse



Reflected Pulse

Slope and Roughness

Slope and Roughness programmed as pgSQL functions

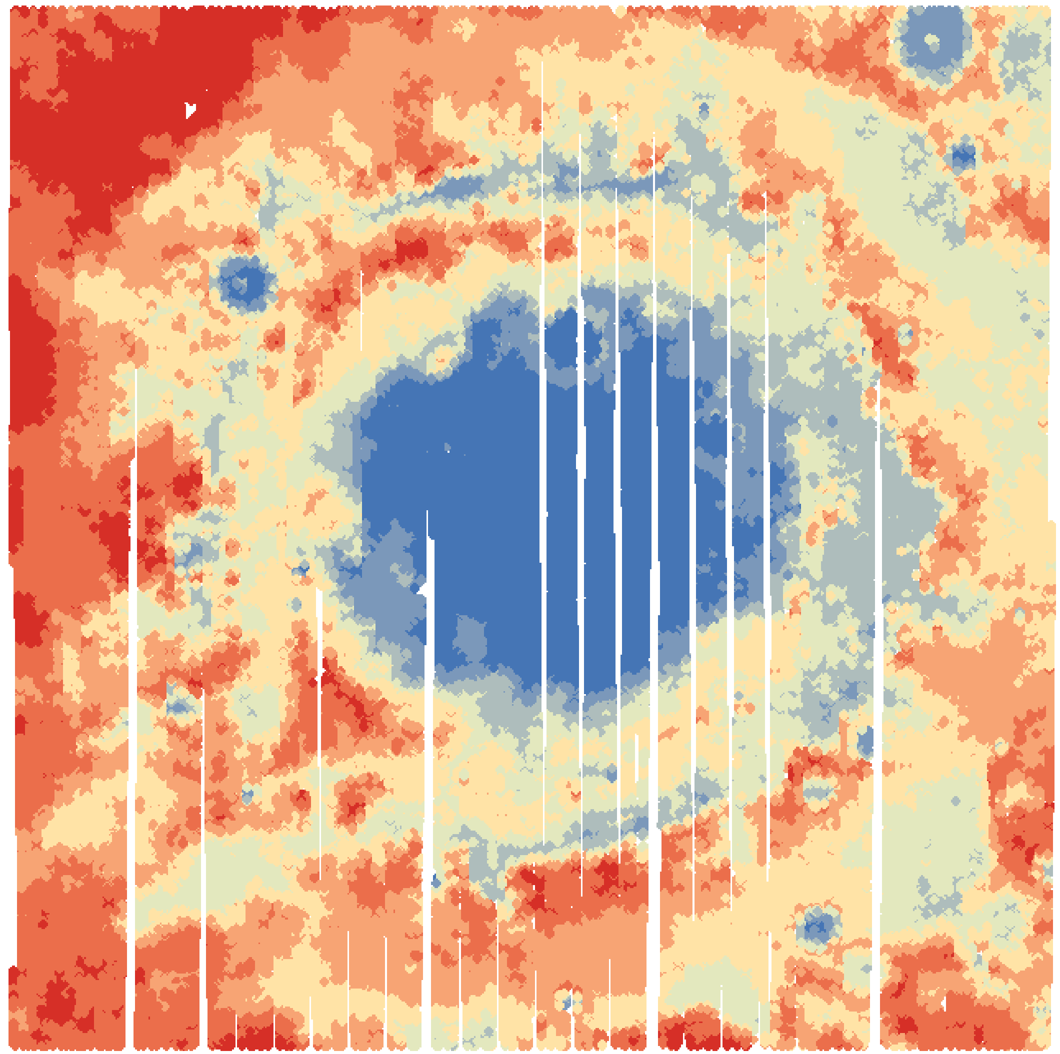
```
slope    (step_width          integer,
          et_center           double precision)
RETURNS real

roughness(sigopt              real,
          mola_range_cm       integer,
          slope               real,
          gamma               real)
RETURNS real
```

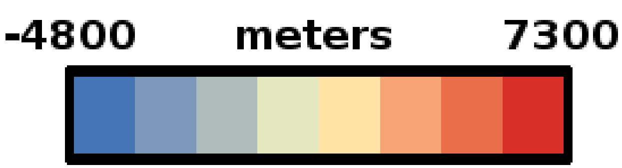
„step_width“ is the only user-dependent parameter, all other values are the result of the SELECT statement.

Topography

Moon,
Kaguya/LALT

Mare Orientale:
Topography



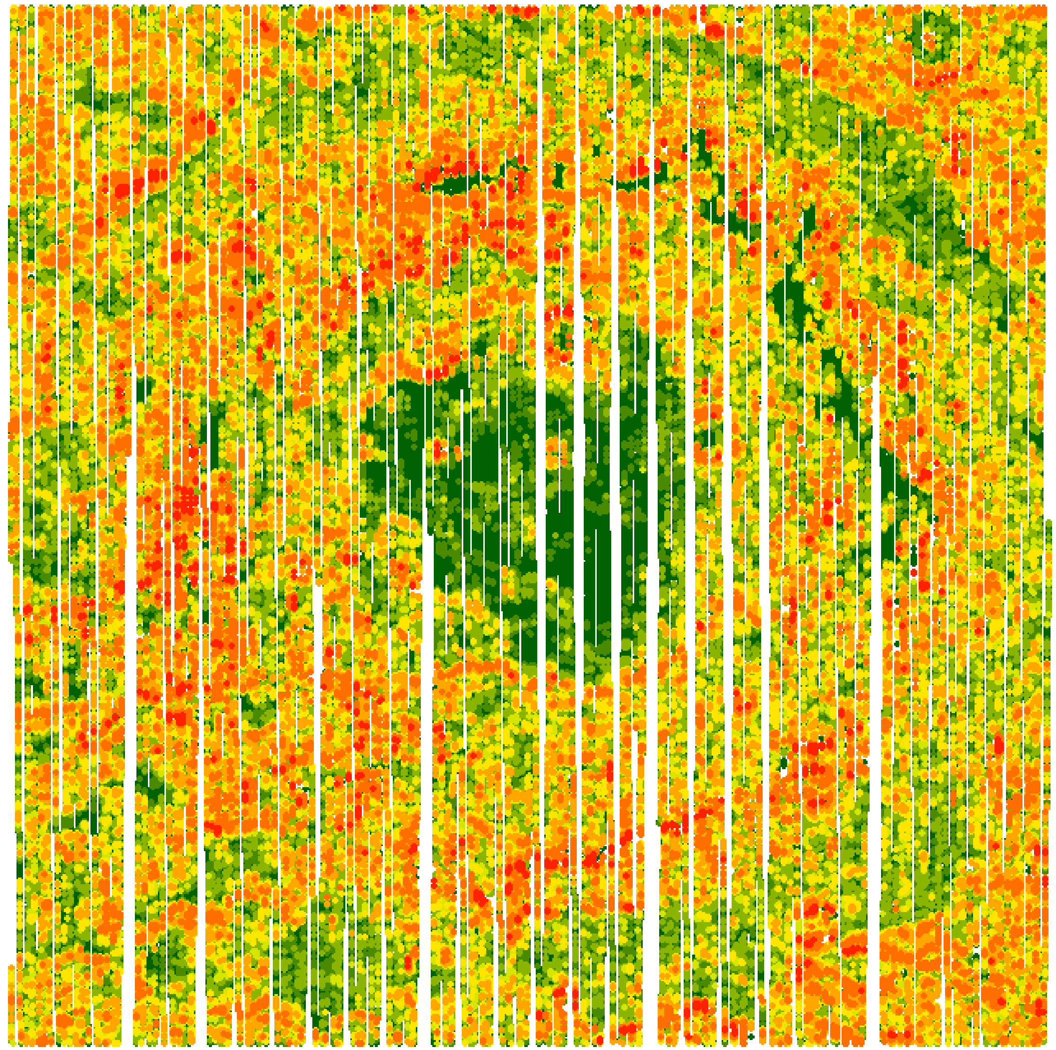


Slope

Moon,
Kaguya/LALT

Mare Orientale:
Slope

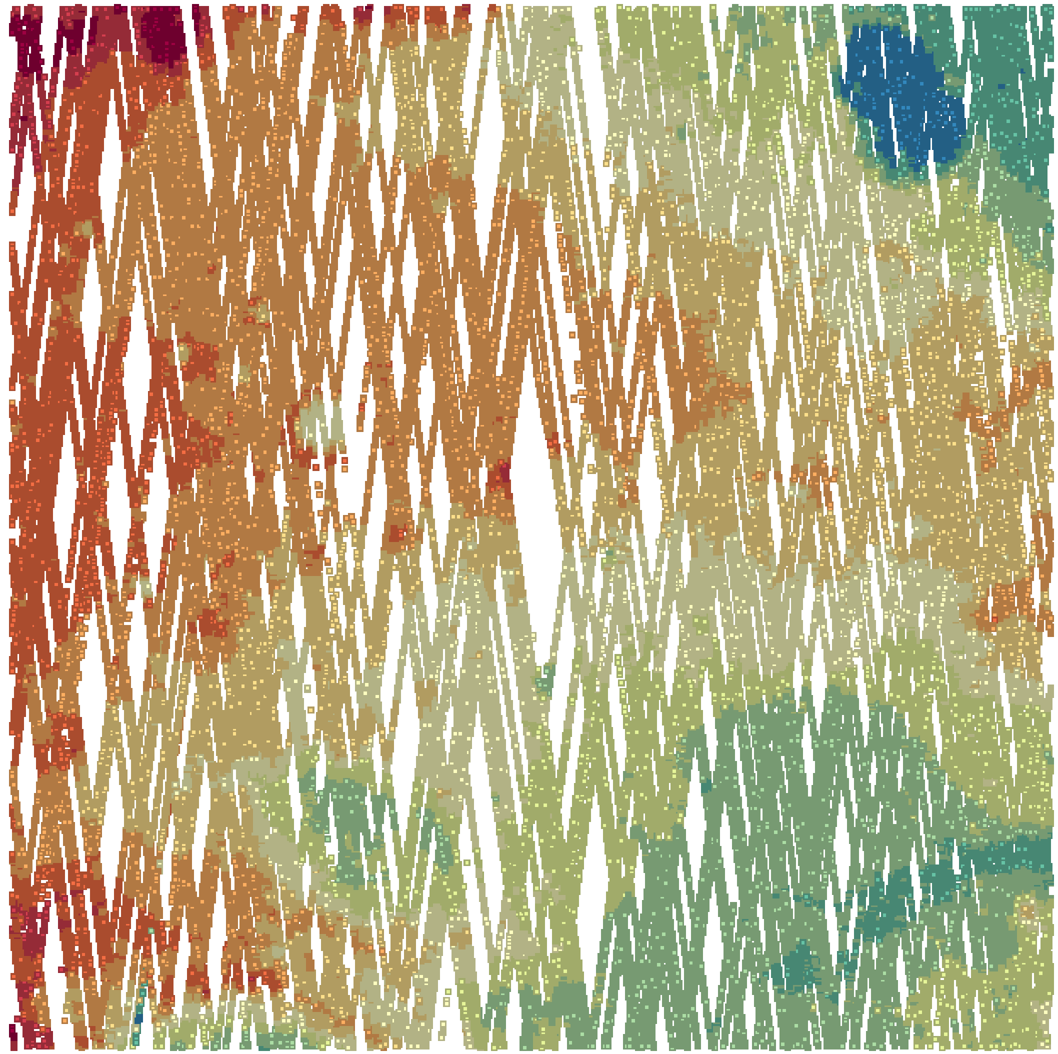
(no roughness, as there is no pulse width available)

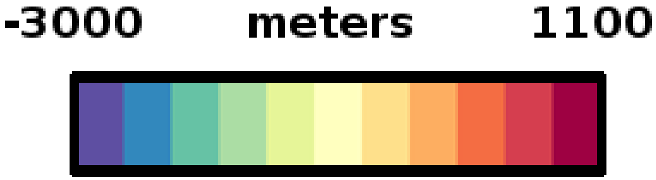


Topography

Mars,
MGS/MOLA

Eberswalde crater:
Topography

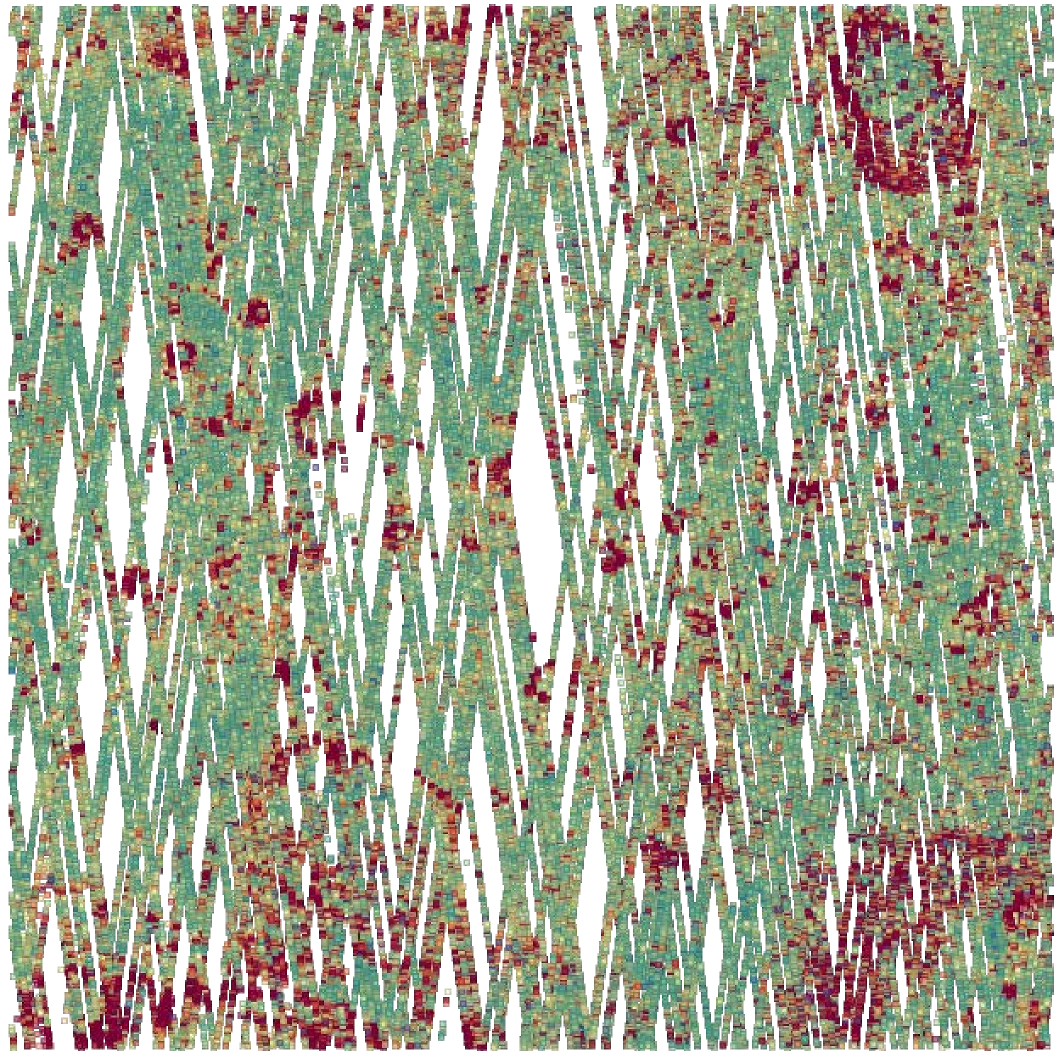




Roughness

Mars,
MGS/MOLA

Eberswalde crater:
Roughness



Analyzing scientific performance for upcoming missions

Crossing points

- Intersection points of laser altimeter profiles (crossover points) are providing a differential height measurement.
- This “observable” can be used to measure the tidal deformation or other geodetic parameters of a planetary object.
- Crossover points are occurring naturally on a polar orbit.
- As the actual ranging performance of the laser altimeter is not known yet we are finding all mutual crossover points based on the current mission orbit and pointing scenario.

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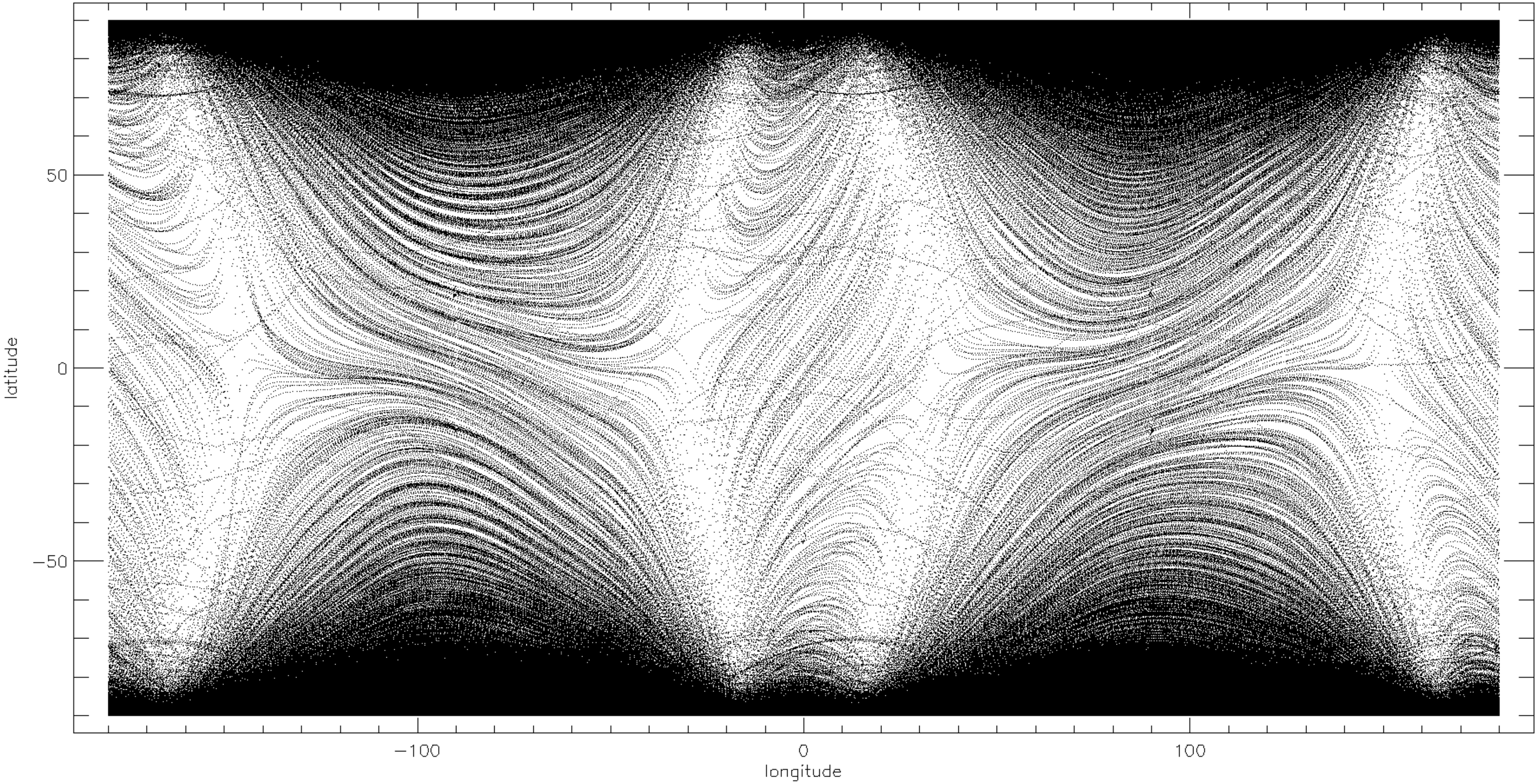
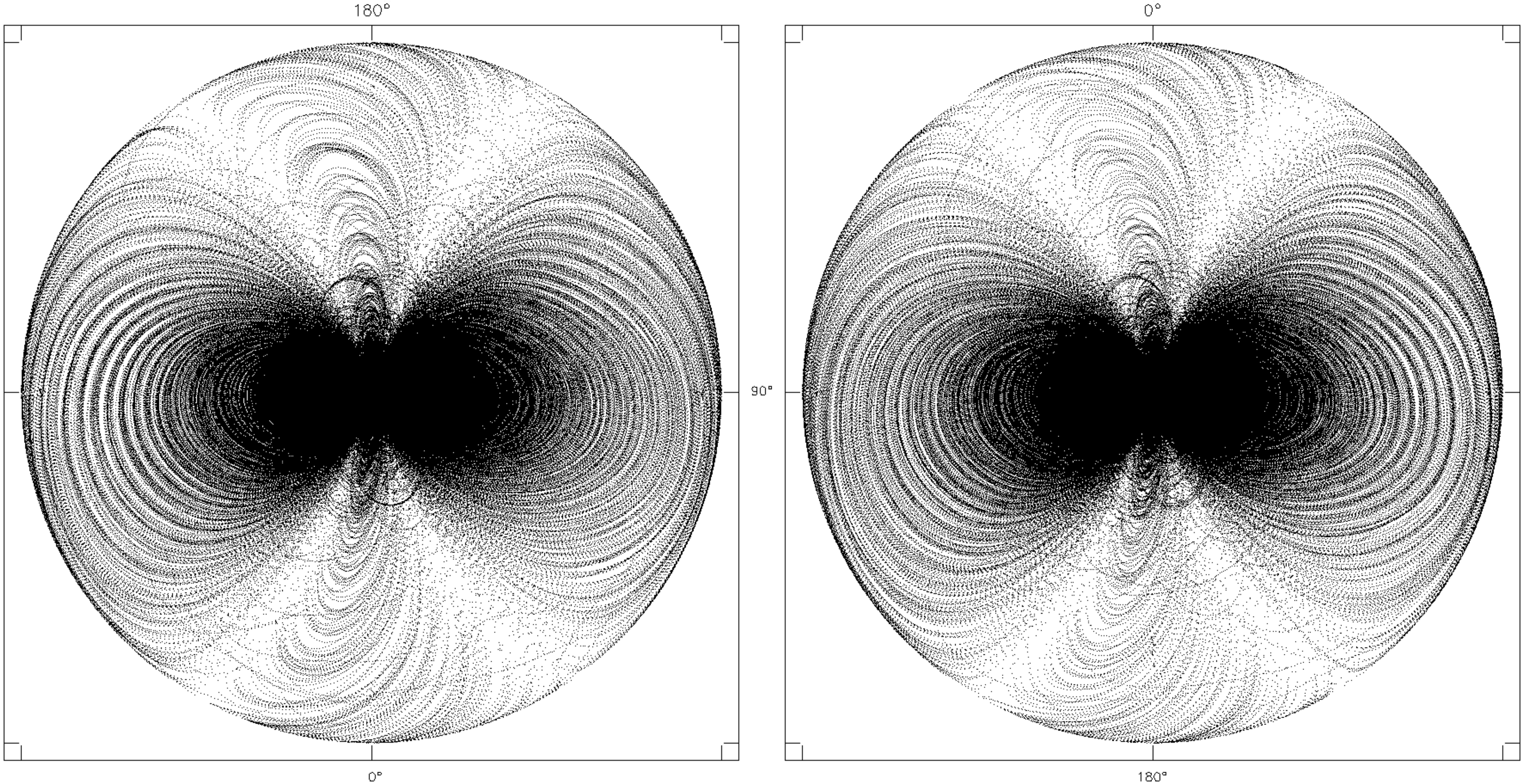
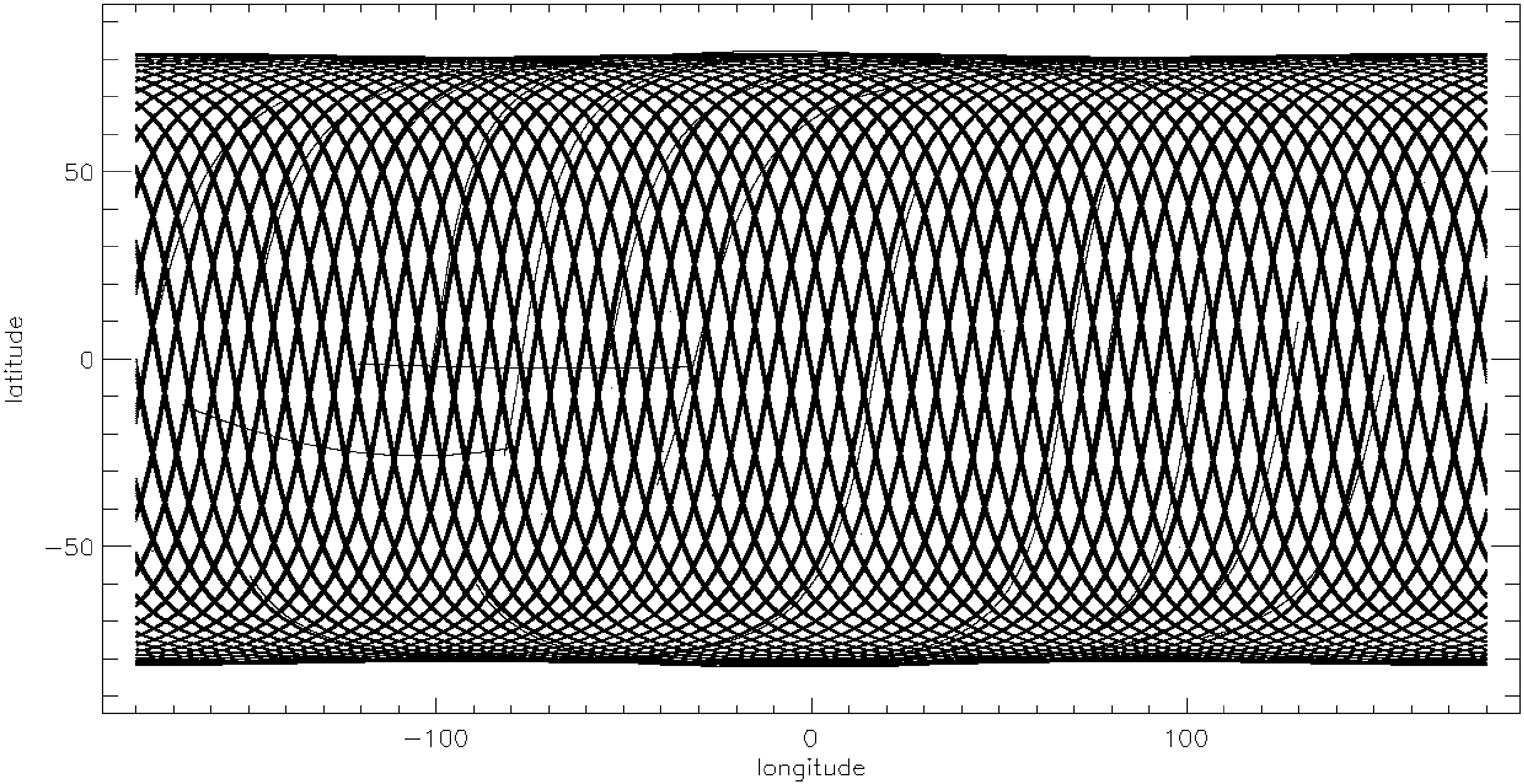
39,873,006 BELA crossings (global)



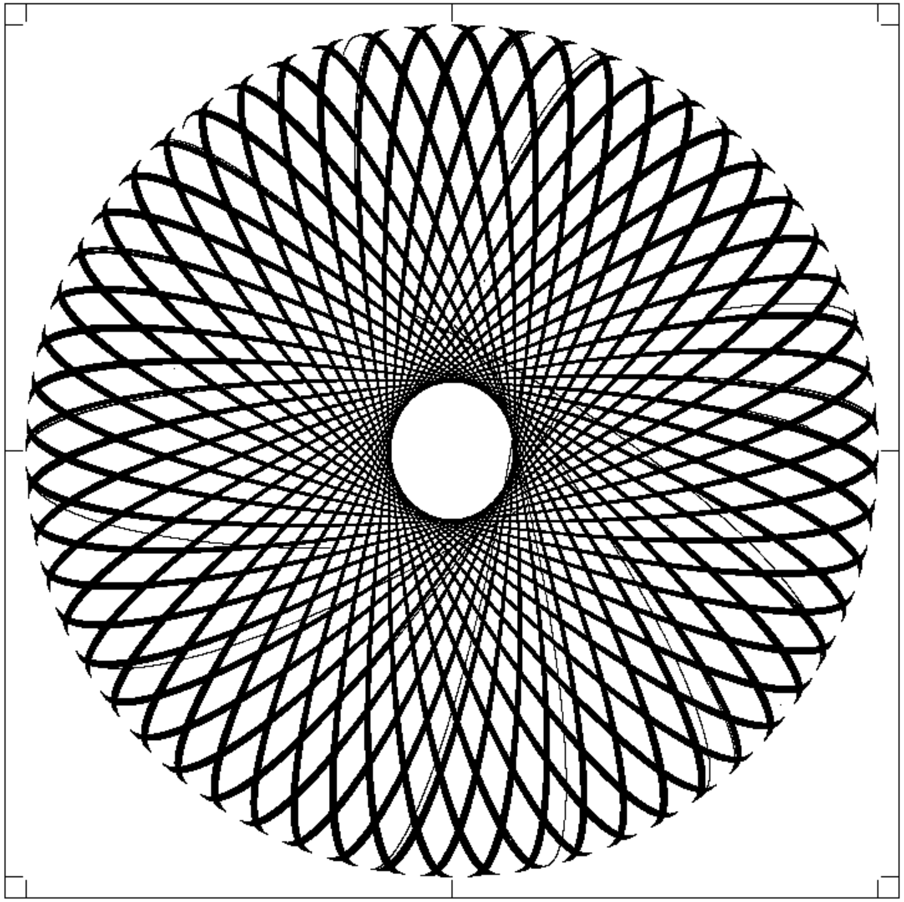
39,873,006 BELA crossings (north and south)

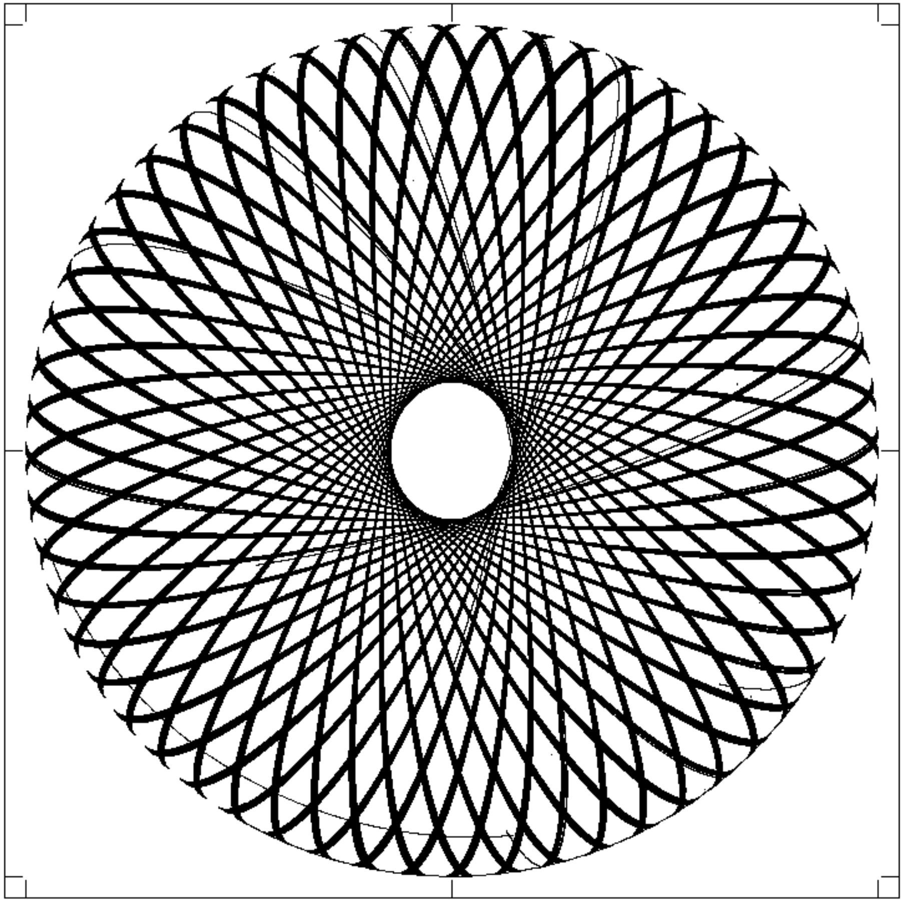


GALA tracks (global)

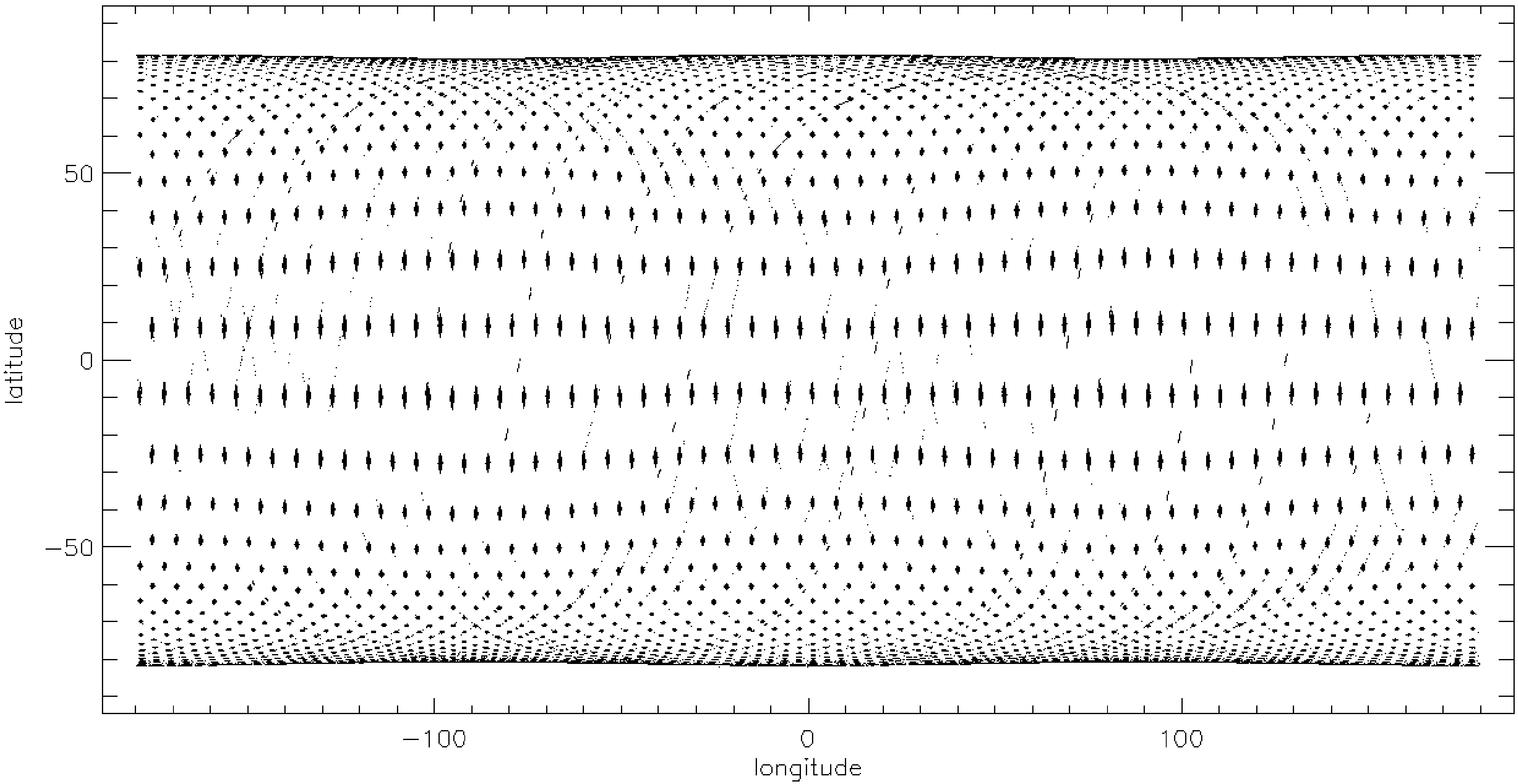


GALA tracks (north and south)

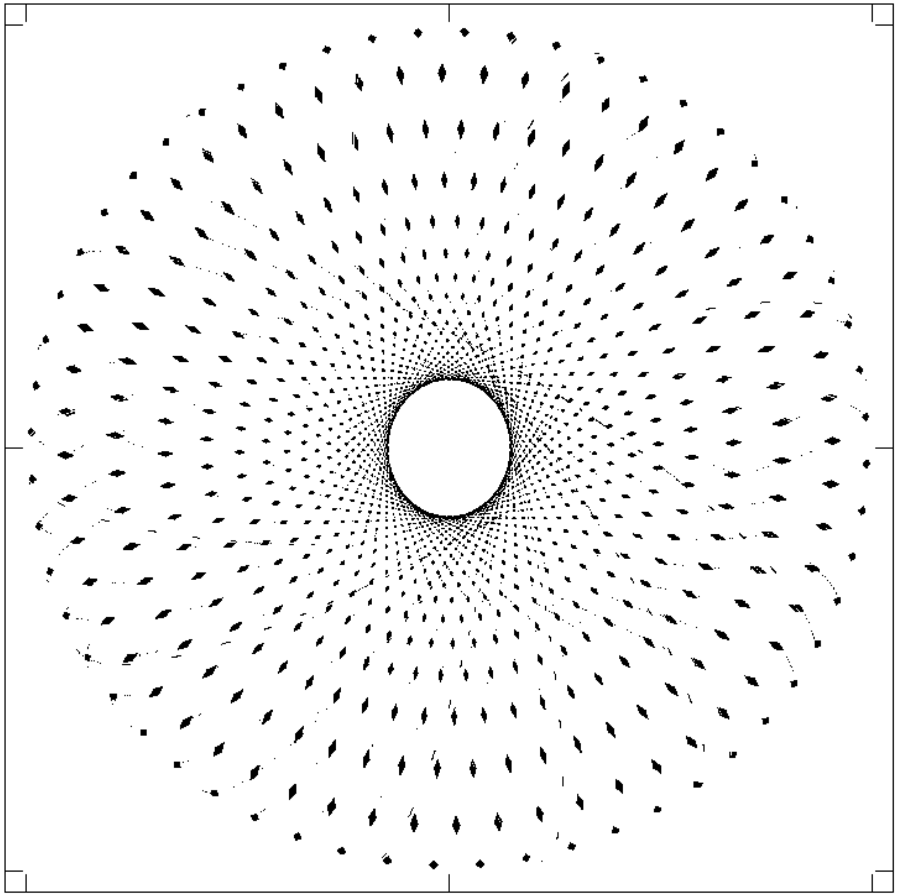


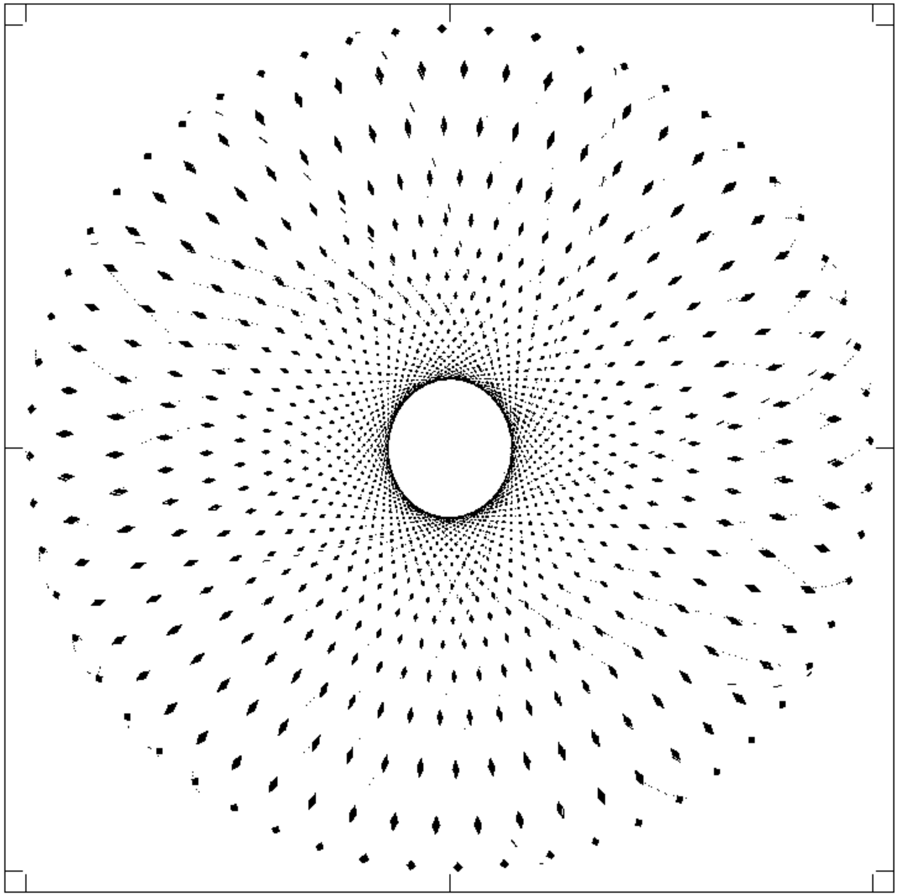


685,667 GALA track crossings (global)



GALA track crossings (343,885 north and 341,782 south)





Crossover analysis - Conclusion

- BepiColombo orbit is well designed for BELA measurements

- Final JUICE orbit (GCO500) must be further optimized for GALA measurements

Co-registration of image and laser products

Co-registration - Method

- **Aim**: Finding conjugate points of laser altimeter footprints in a digital terrain model (DTM) + determining the transformation of the co-registration

- **Method**: Minimization of height differences by a non-linear least-squares adjustment

$$\sum_i \left[r_{\mathrm{DTM}}^i - r_{\mathrm{LA}}^i\right]^2 \rightarrow \mathrm{min.}$$

  - ✓ Mathematical formalism which permits different forms of parameterization (e.g. solving for rotation parameters or laser altimeter pointing offsets)
  - ✓ Sub-pixel accuracy through cubic B-splines interpolation
  - ✓ Allows detection of outliers in the data sets

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Co-registration - Implementation

- **Implementation:**
  - Spacecraft (instrument) and planetary body independent implementation
  - Realization in Python with interfaces to external libraries:
    - Interaction with the DTM via a self-designed Python interface to the VICAR library
    - Interaction with laser altimeter data via interface to the PostgreSQL database (*psycopg*)
    - Least-squares adjustment and interpolation using *numpy* and *scipy* Python modules
    - Plotting with *matplotlib* module

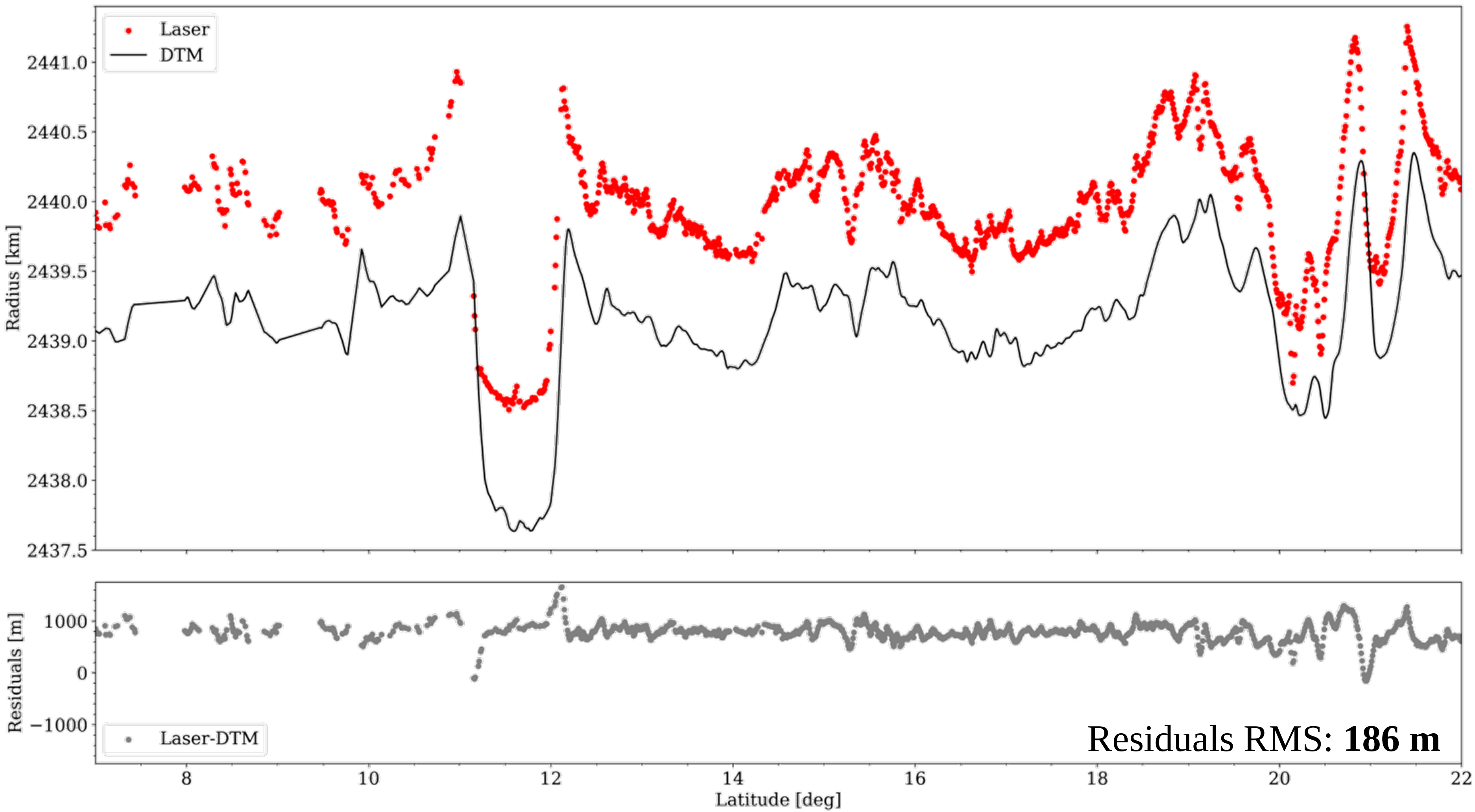
Co-registration – Results

- **Example – MESSENGER data:**
  - Mercury Laser Altimeter profile: *mlascirdr1504230326*
  - Stereo DTM with 222 m/px constructed by photogrammetric adjustment of stereo images from the Mercury Dual Imaging System (*Preusker et al.*, *2017*, *PSS*)
  - Obtained corrections (for the laser profile):
    - Along track: -2764 ± 32 m
    - Cross track: 60 ± 29 m
    - Radial: -798 ± 2 m

    - After five iterations the RMS of height differences (residuals) was minimized from 186 m to 69 m

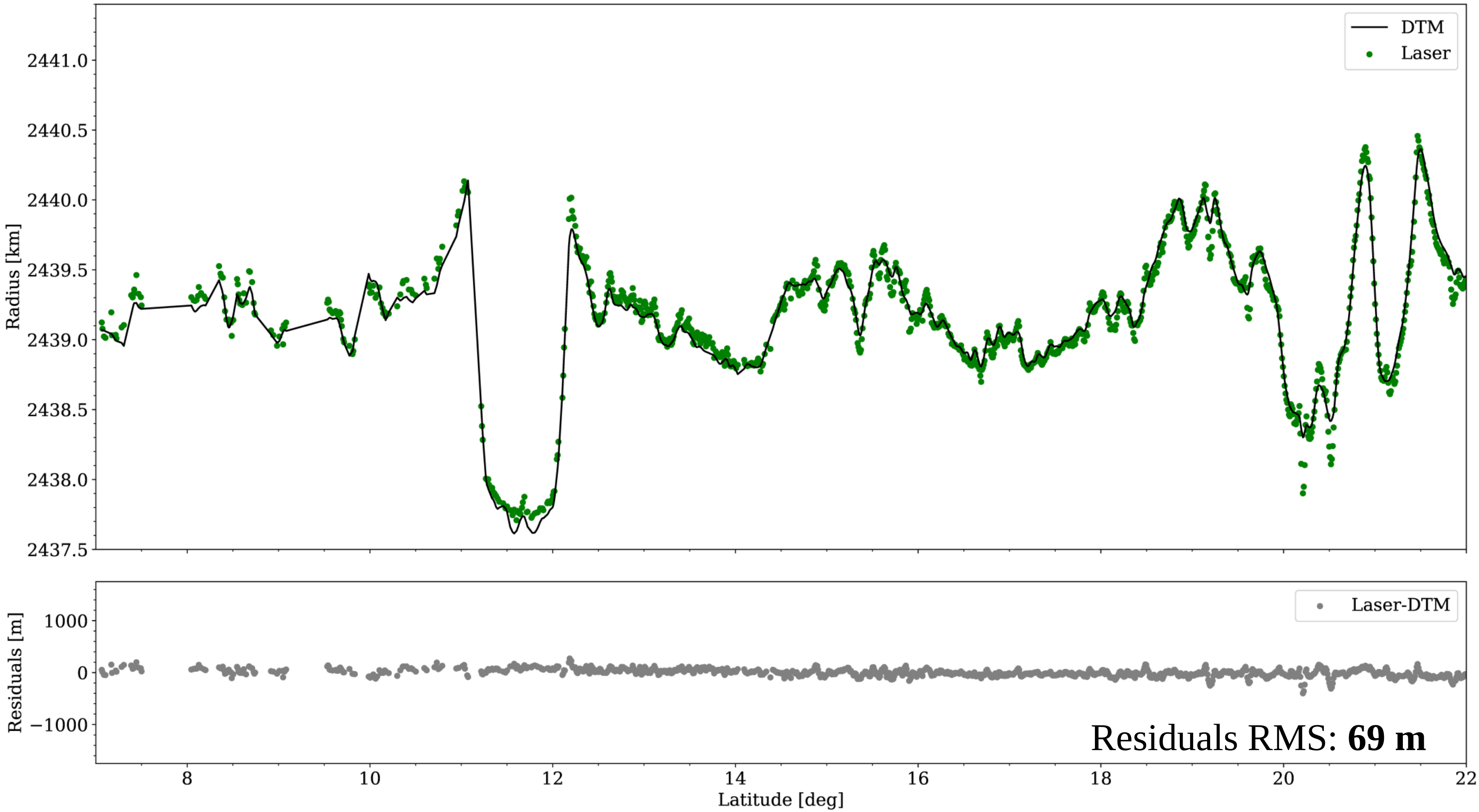
Co-registration – Results

before co-registration



Co-registration – Results

after co-registration



Summary

- At the **DLR Planetary Research Institute** a database for past, ongoing and future **laser altimeter data** is maintained

- The database provides **additional functionality** for deriving higher level products e.g. **surface roughness** or **crossover observations**

- A capability **for joint-analysis of image and laser data** is available

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