Global Topography and Gravity of the Moon Observed by KAGUYA (SELENE)

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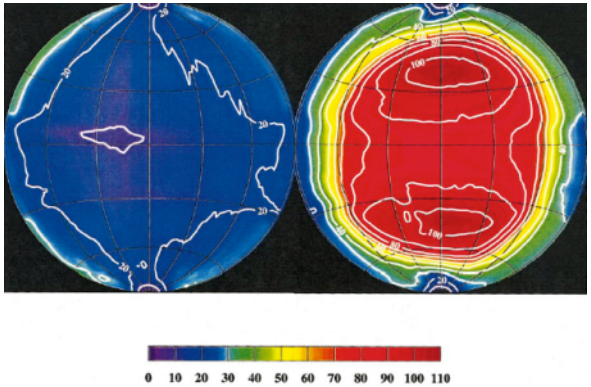
Lunar Science Forum, July 22, 2009

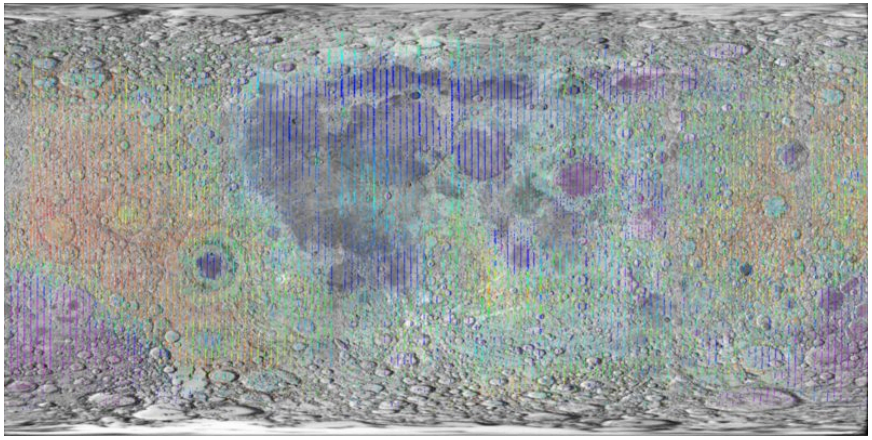
Lunar Gravity and Topography Were Unsolved

Gravity is obtained by orbital tracking of spacecraft.

Synchronous rotation of the Moon prohibits direct gravity measurements over the far side.



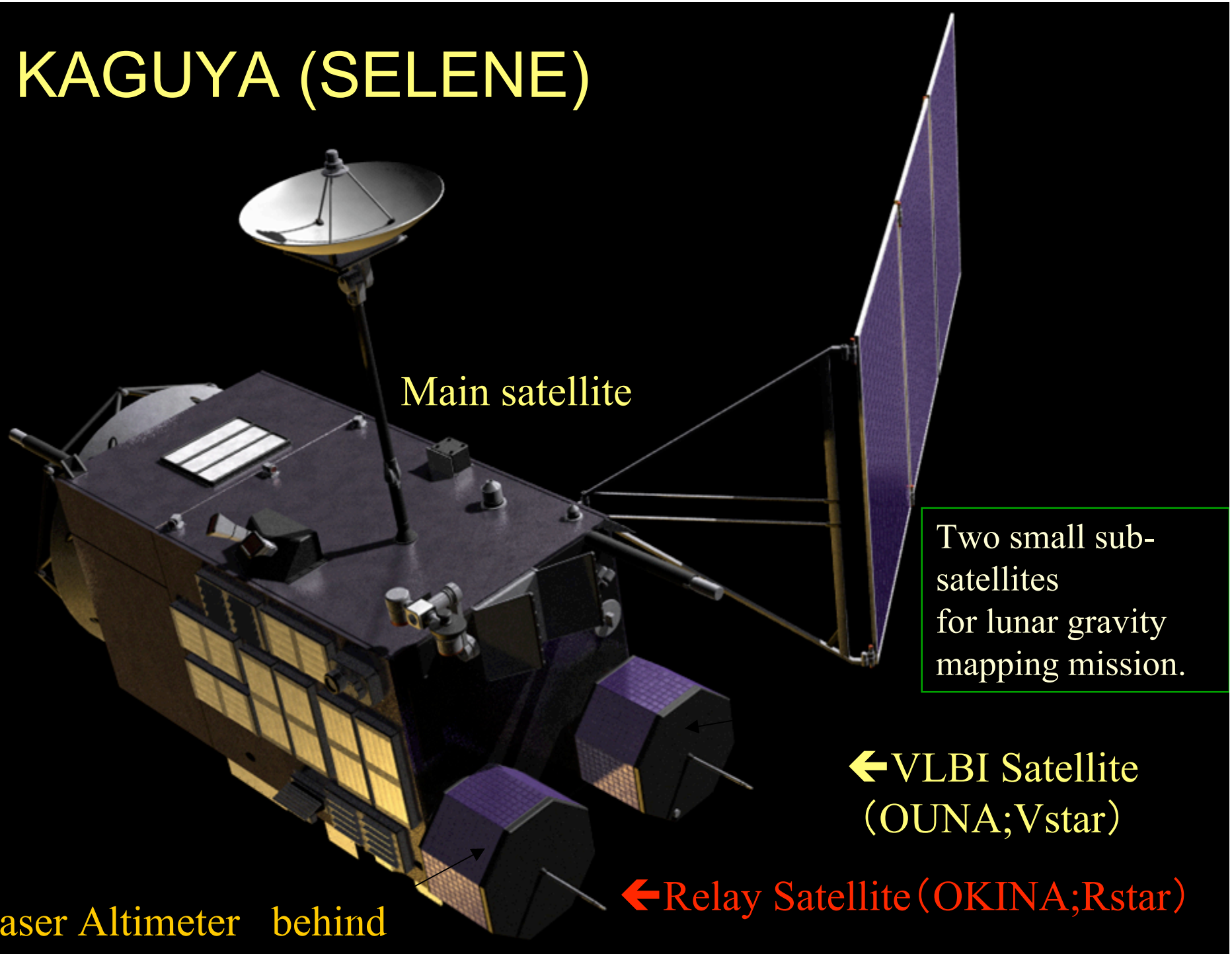
Large uncertainty of far-side (right) gravity in previous models.



Topography by Clementine:

- Laser altimetry 72548 points
- A few 10km resolution.
- Orbital uncertainty 100m.
- Lack of high-latitude data including polar region.

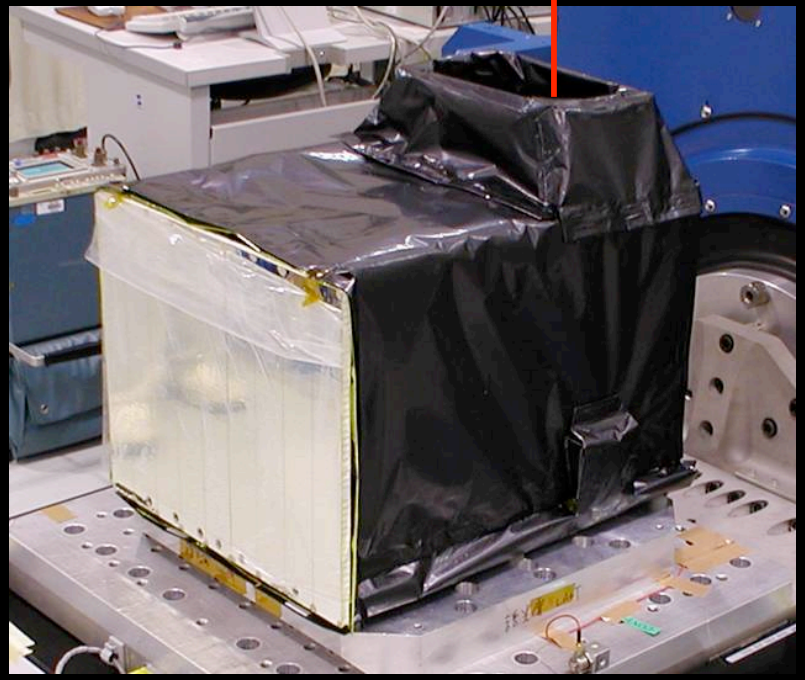
KAGUYA (SELENE)



Laser Altimeter (LALT)

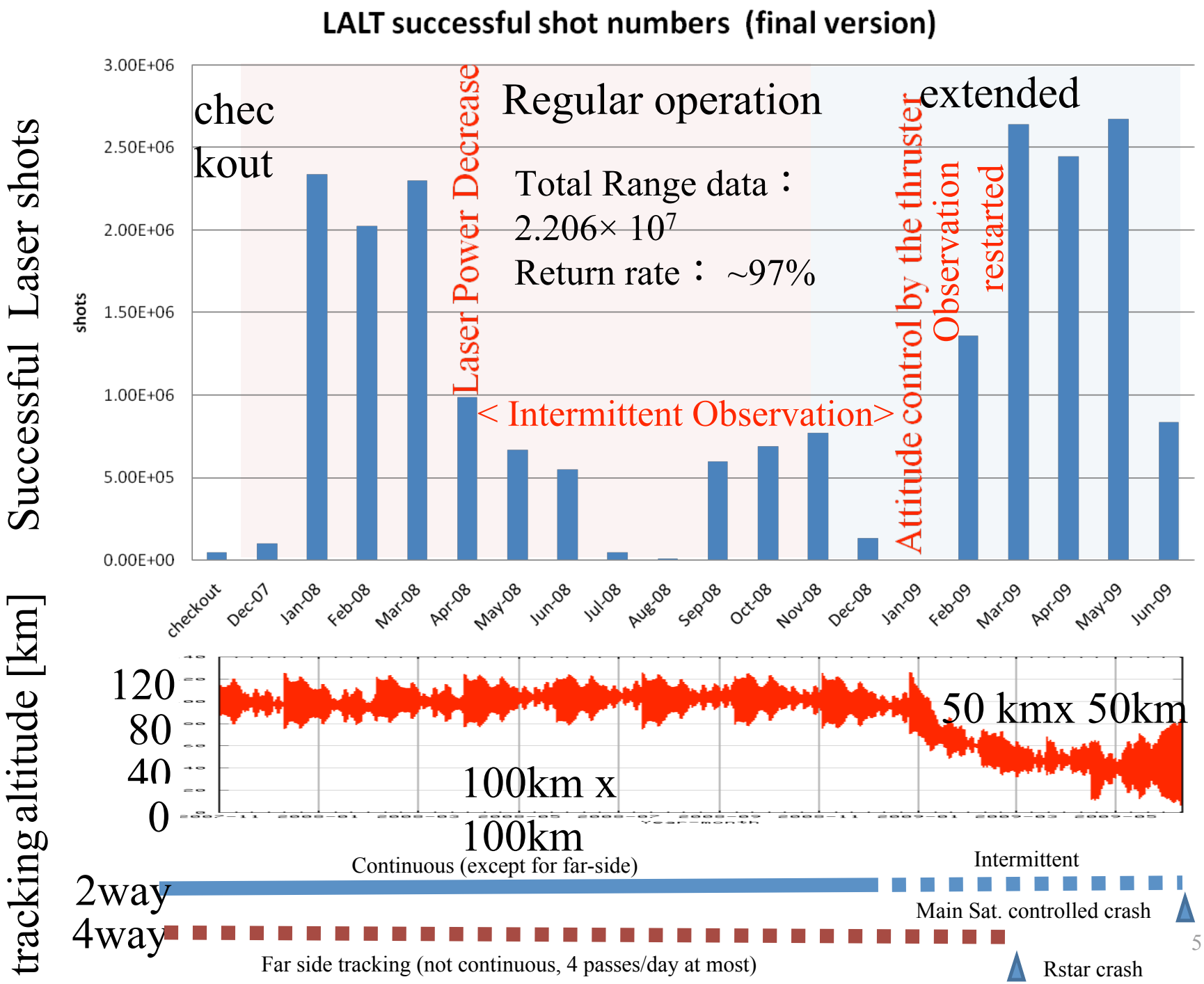
Altitude	~100km	Measurement	1Hz
Resolution	1m	Footprint	40m

Lunar Surface

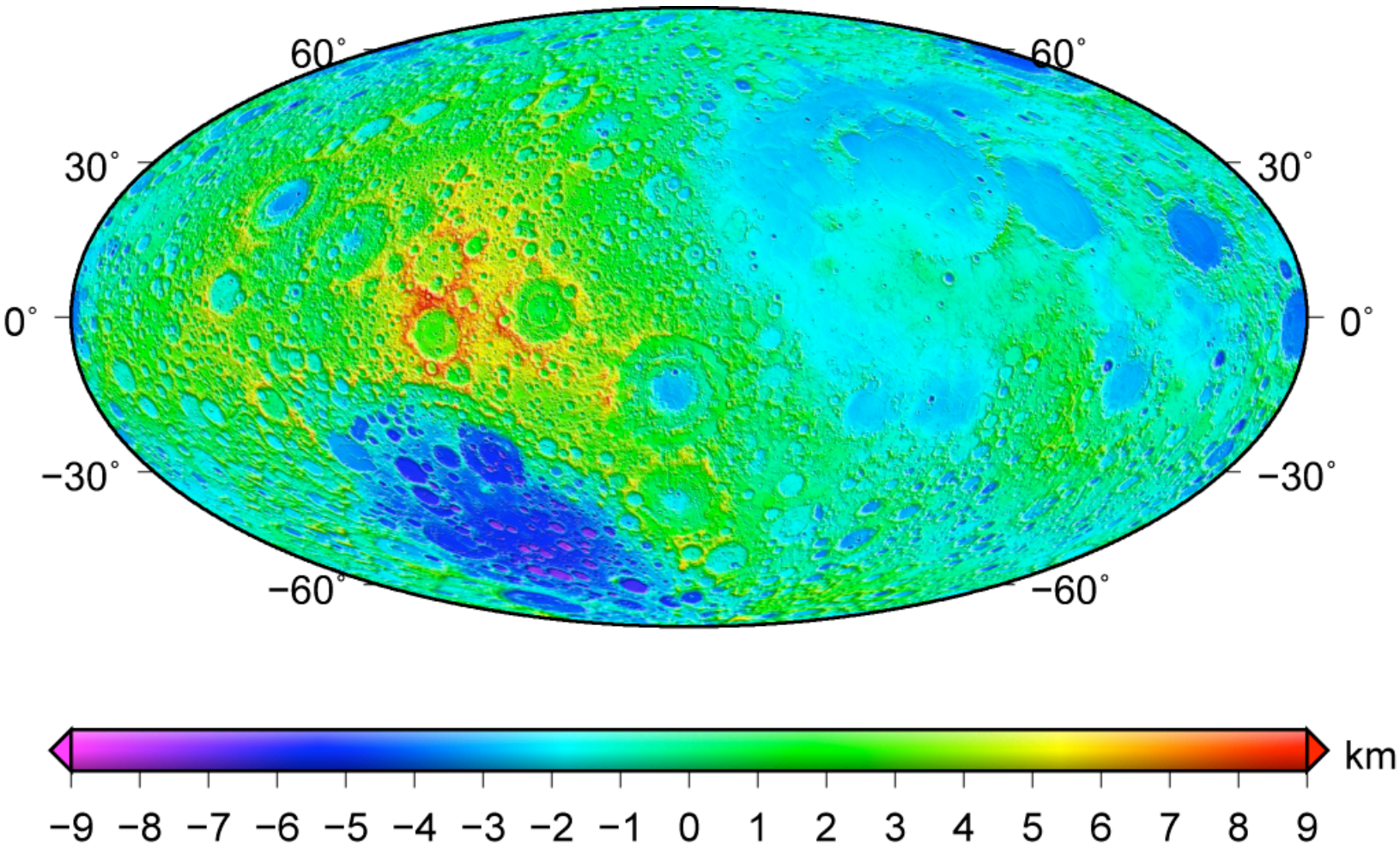


Laser Transmitter/Receiver:
Cr:NdYAG 360* 450*408

LALT Electronics:
241*301*88 mm, 3.75kg

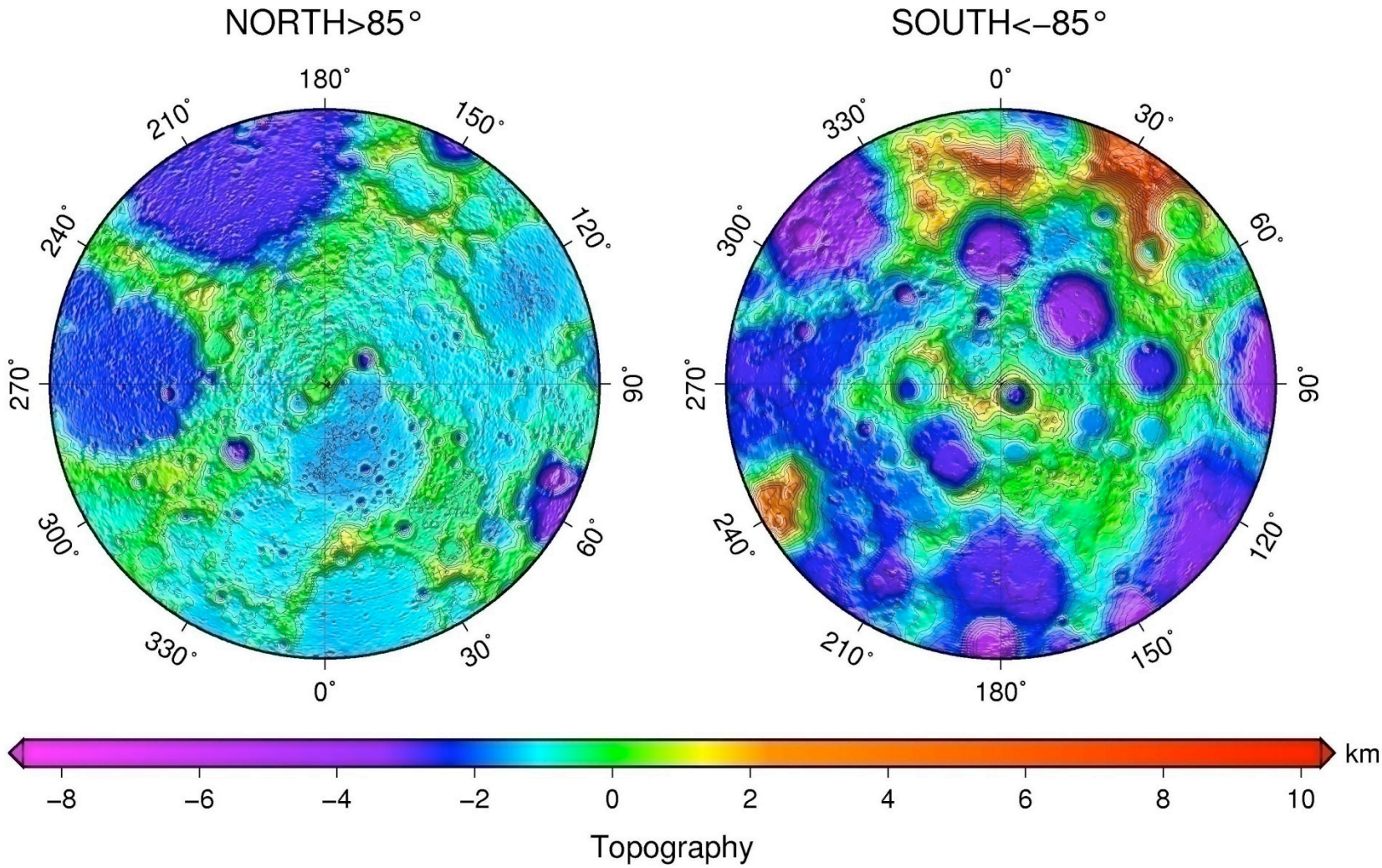

LALT successful shot numbers (final version)
Successful Laser shots
shots
3.00E+06
2.50E+06
2.00E+06
1.50E+06
1.00E+06
5.00E+05
0.00E+00
chec
kout
Regular operation
extended
Laser Power Decrease
Attitude control by the thruster
Observation
restarted
Total Range data：
2.206× 10^7
Return rate： ~97%
< Intermittent Observation>
checkout
Dec-07
Jan-08
Feb-08
Mar-08
Apr-08
May-08
Jun-08
Jul-08
Aug-08
Sep-08
Oct-08
Nov-08
Dec-08
Jan-09
Feb-09
Mar-09
Apr-09
May-09
Jun-09
tracking altitude [km]
120
80
40
0
50 kmx 50km
100km x
100km
Continuous (except for far-side)
Intermittent
2way
4way
Main Sat. controlled crash
Far side tracking (not continuous, 4 passes/day at most)
Rstar crash

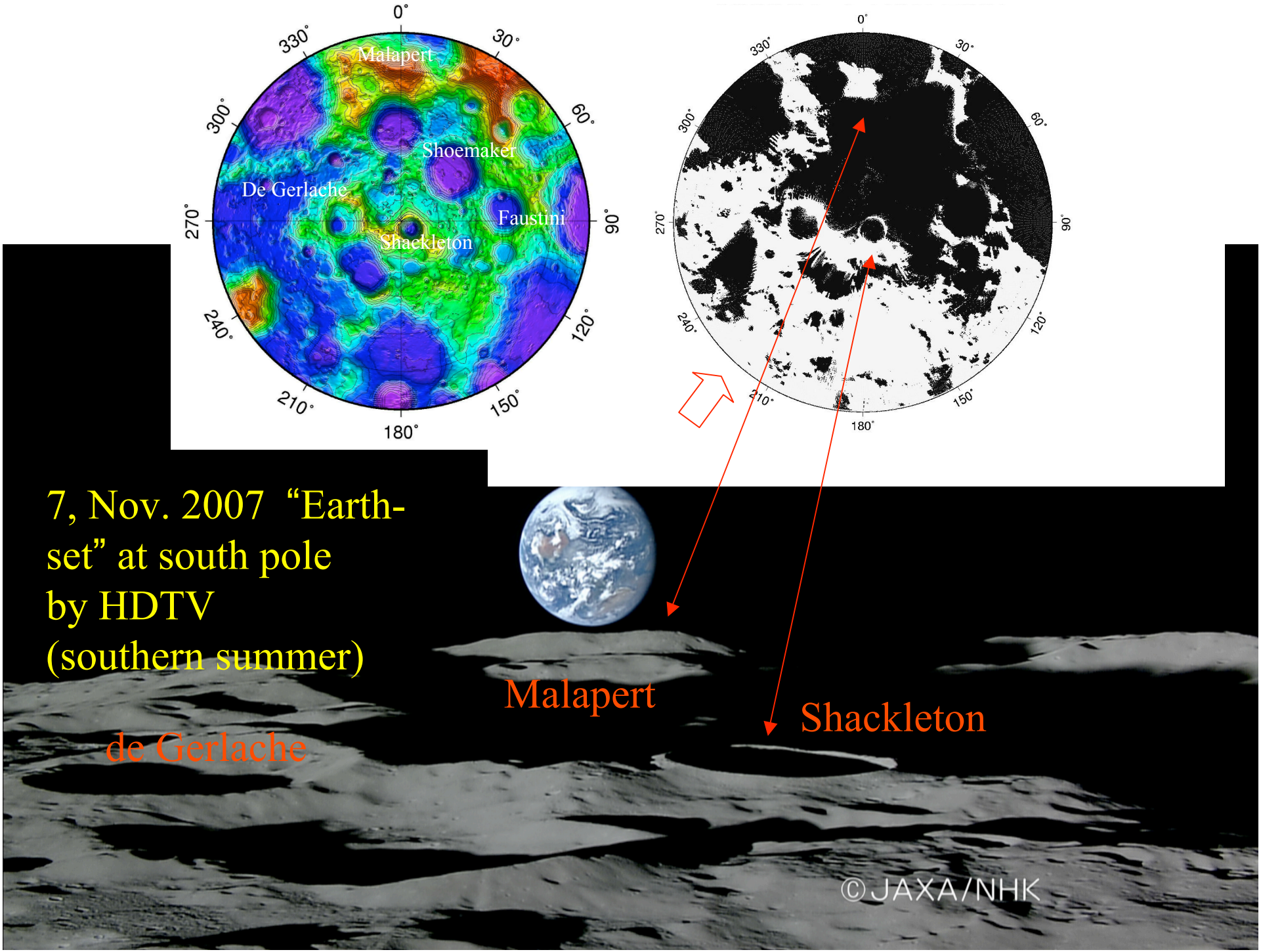
Topography from LALT (Laser ALTimeter) data



Resolution: 1.5 km (lat) x (a few -10) km (lon) at the equator

Polar topography (>85deg)



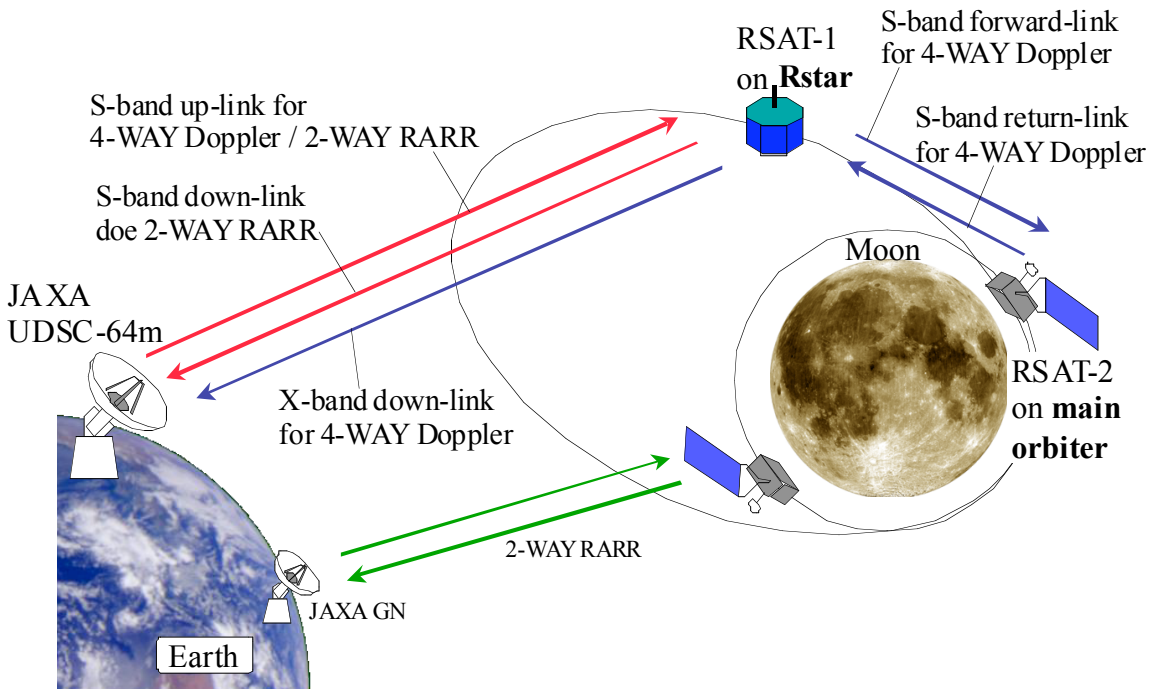

0°
30°
60°
90°
120°
150°
180°
210°
240°
270°
300°
330°
Malapert
Shoemaker
De Gerlache
Faustini
Shackleton
7, Nov. 2007 "Earth-set" at south pole by HDTV (southern summer)
Malapert
Shackleton
de Gerlache
©JAXA/NHK

KAGUYA measures Far-Side Gravity by the Relay Satellite OKINA

Using 4-way Doppler tracking via the relay satellite OKINA, we first directly measure the gravity field over the far side of the Moon.

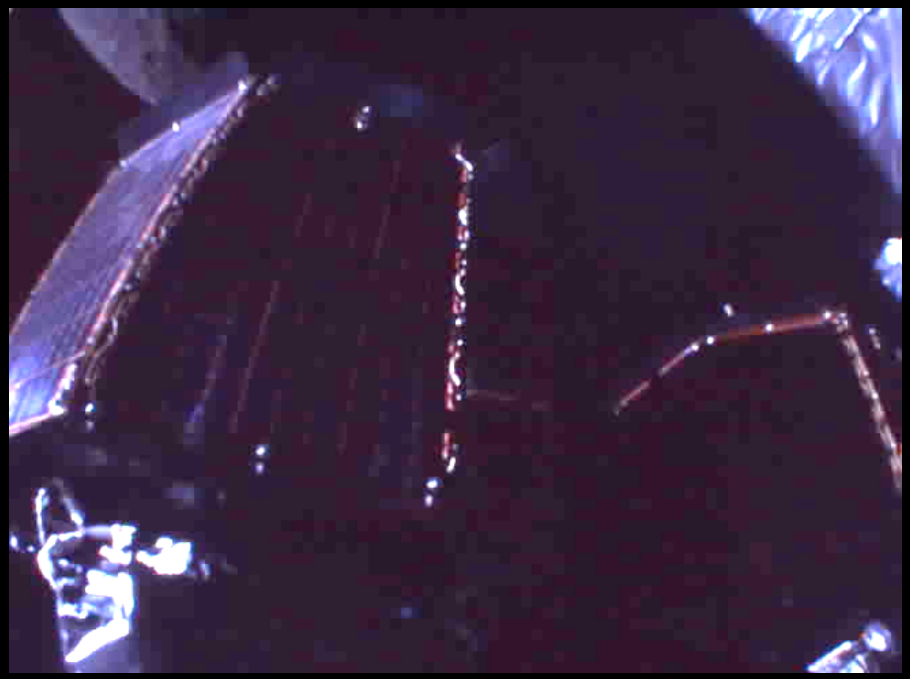
KAGUYA(MAIN)
Circular polar orbit with altitude 100km.
t ~ 1 hr 58m.

OKINA
Elliptic polar orbit with altitude ranging from 120 to 2395 km
t ~ 4 hr 5m

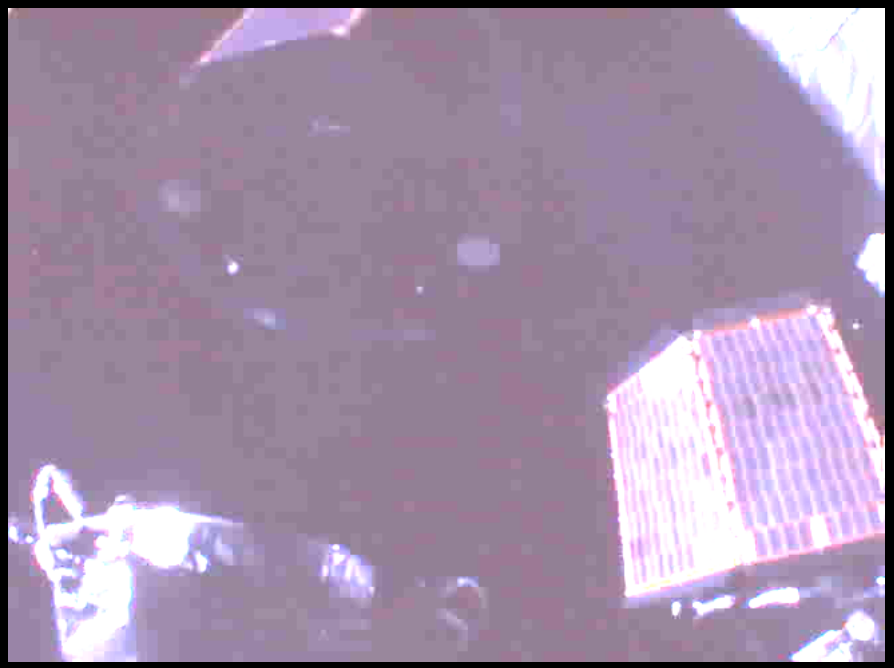


Successful Launch of KAGUYA (SELENE) Sep.14, 2007

Deployment of Relay Satellite Oct.9, 9:35JST



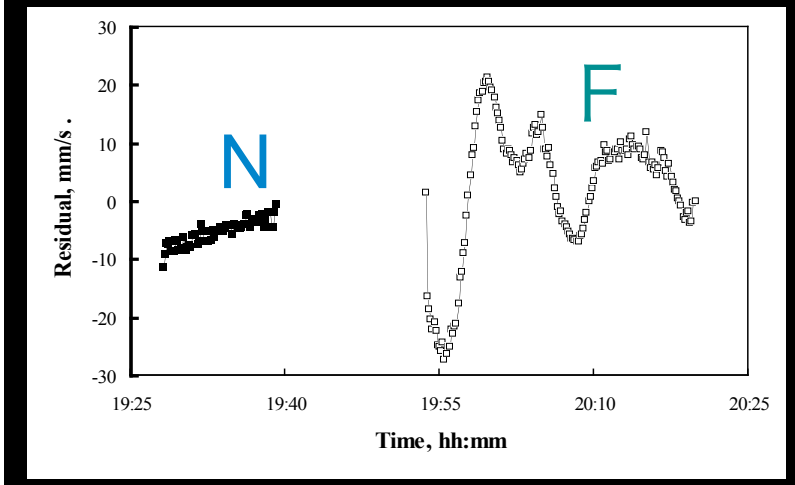
Before deployment

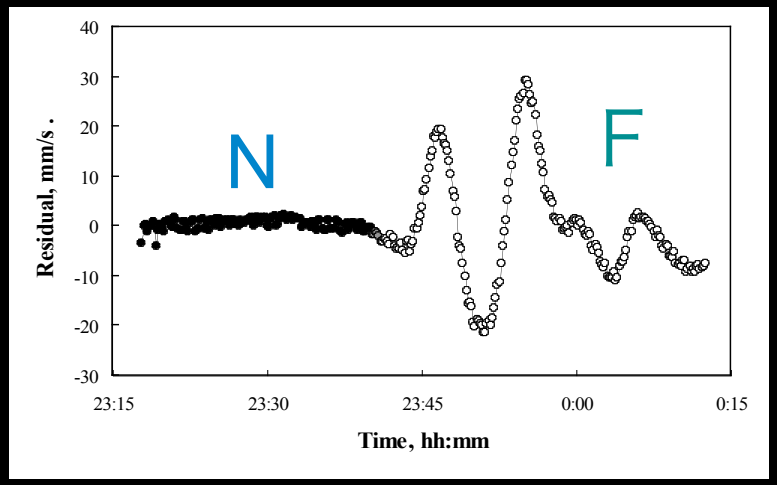


After deployment

First success in far-side gravity measurement on Nov. 5, 2007

Results From Initial Check Out Phase: 4-way Doppler (O – C)

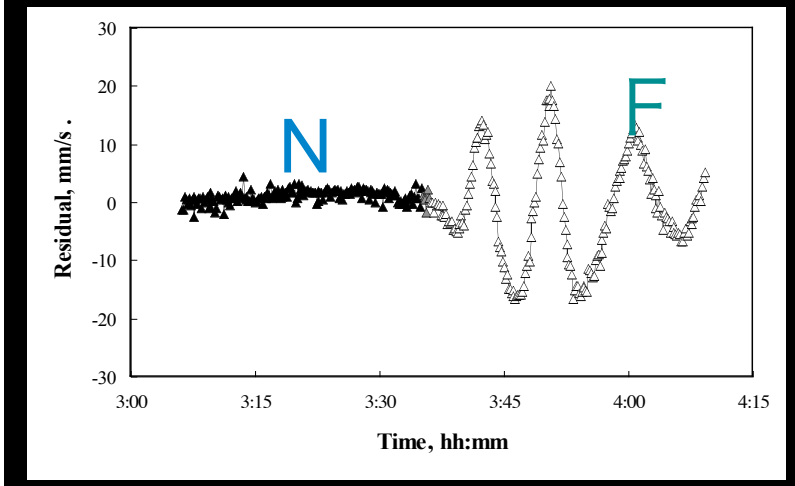




Upper Left: 19:27 to 20:20 on Nov. 5

Upper Right: 23:17 on Nov. 5 to 0:12 on Nov. 6

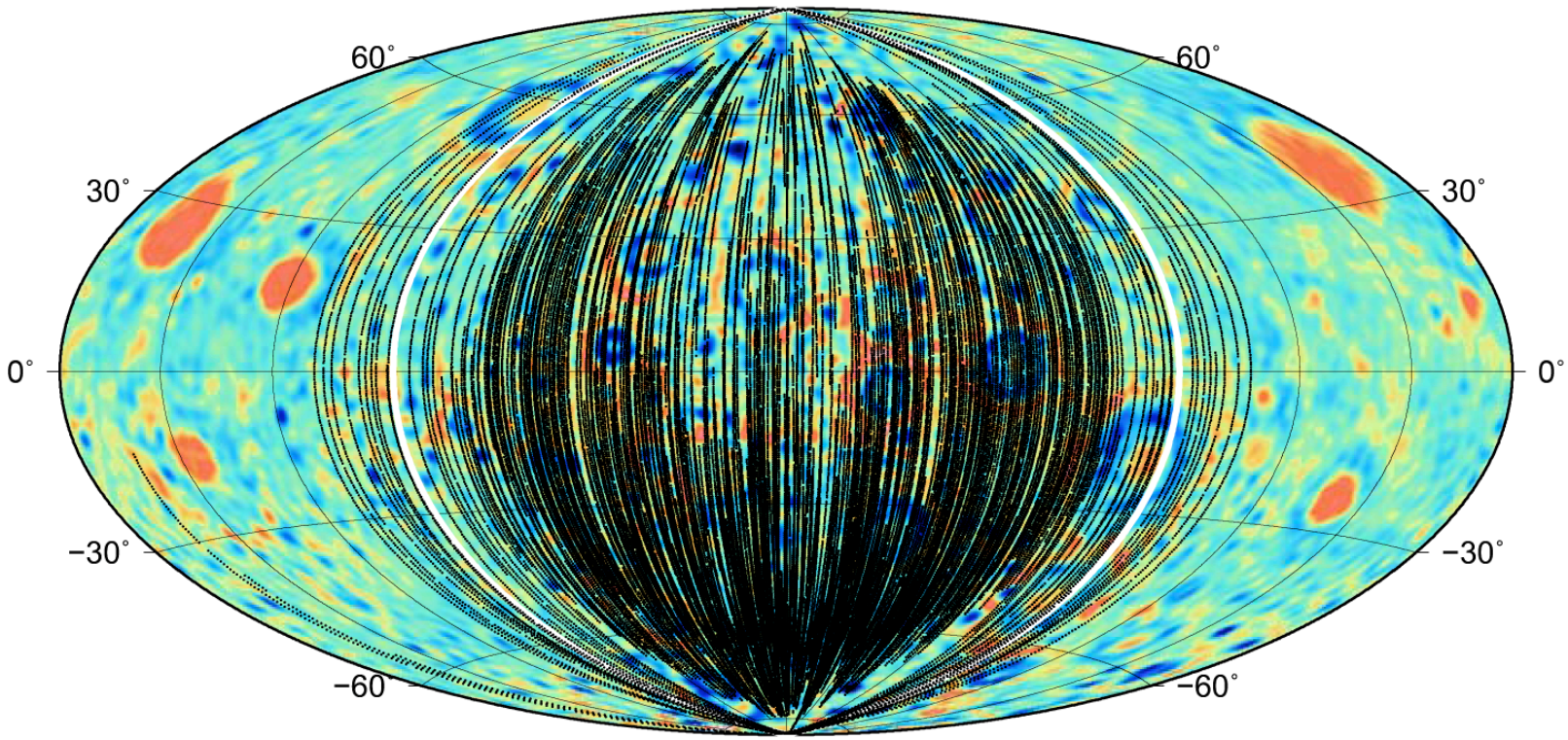
Lower Left: 3:06 to 4:09 on Nov. 6



- ***Residuals*** of observed Doppler data from a prediction based on LP100K lunar gravity model.
- Over the near side, variation of residuals is smaller than ***5 mm/s***. In contrast, variation over the far side is as large as ***30 mm/s***.

4-way Doppler data coverage achieved during the lifetime of Rstar

071031−090130



Far-side centered.

White solid line indicates the boundary between the near and the far-sides

Data and analysis setting for SELENE Gravity Model version h (SGM100h)

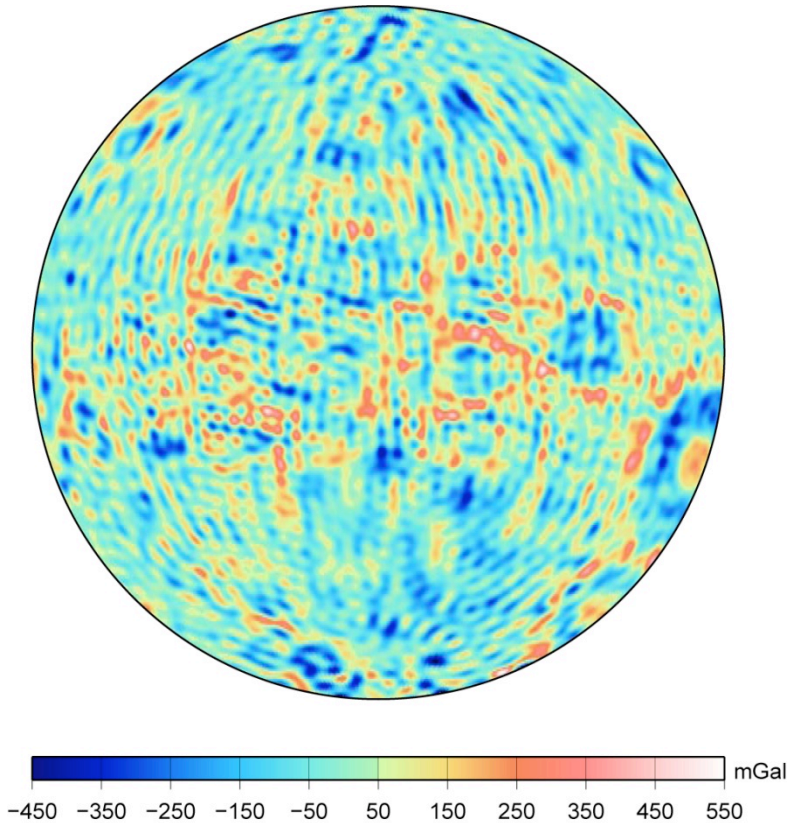
14 month-tracking data (by the end of 4-way Doppler)

- SELENE : 2007.10.20～2008.12.26 & 2009.01.30
  Doppler + range
- Historical: LO I-V, A15/16ss, Clementine,
  LP nominal mission, SMART-1

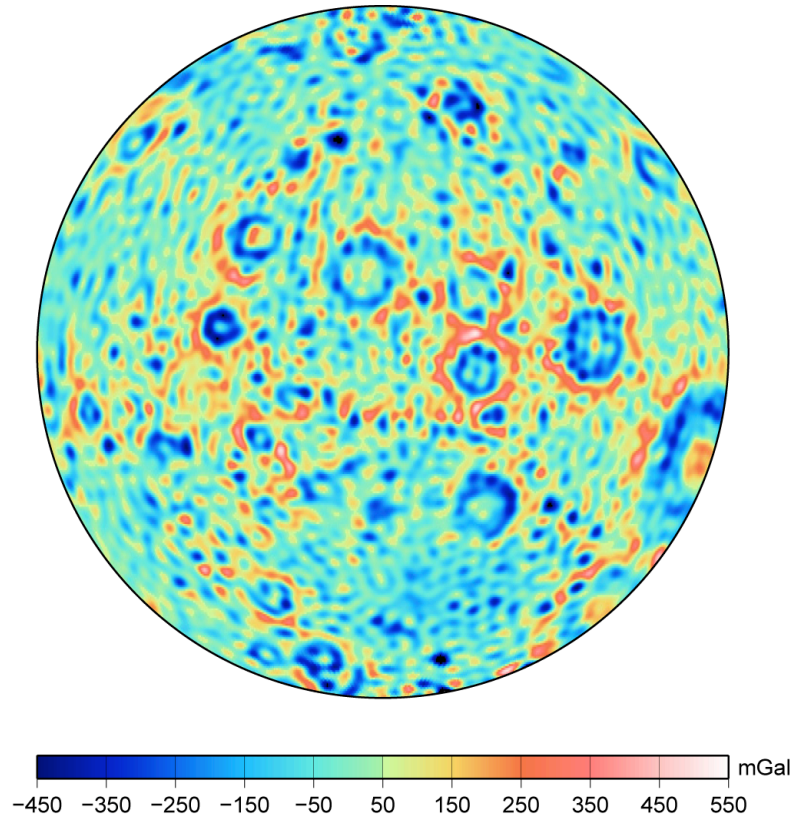
Setting

- GEODYN II, SOLVE system
- Expanded up to degree and order 100
- Ephemeris: DE421
- A Kaula-type constraint of $3.6 \times 10^{-4}/n^2$
- Solar radiation pressure model
  SELENE Main: box + wing
  SELENE R/Vstar and other satellites : cannonball
- Mean arc length of Rstar = 2.6 days
- VLBI data not included

Old and new views of far-side gravity field

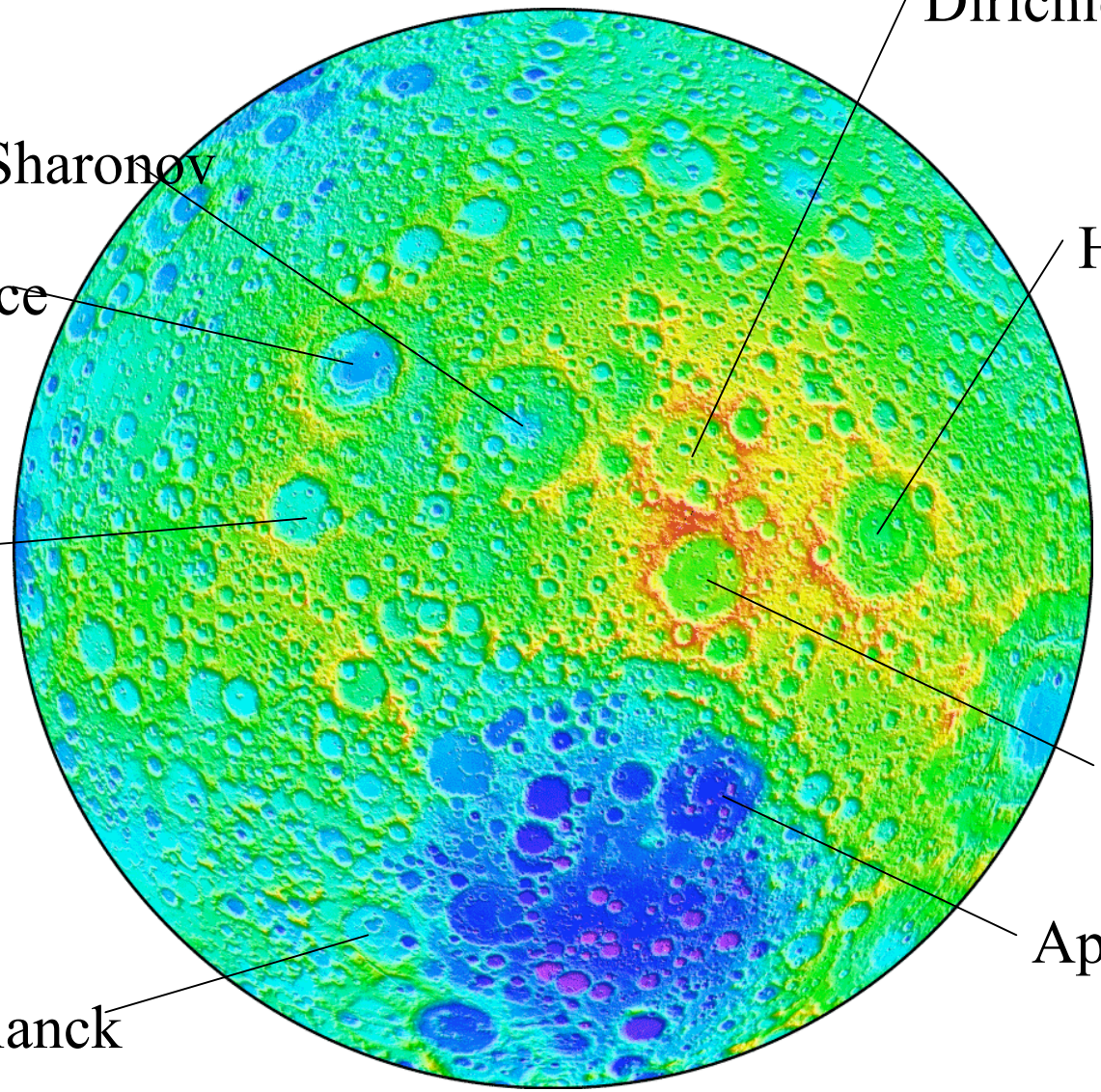


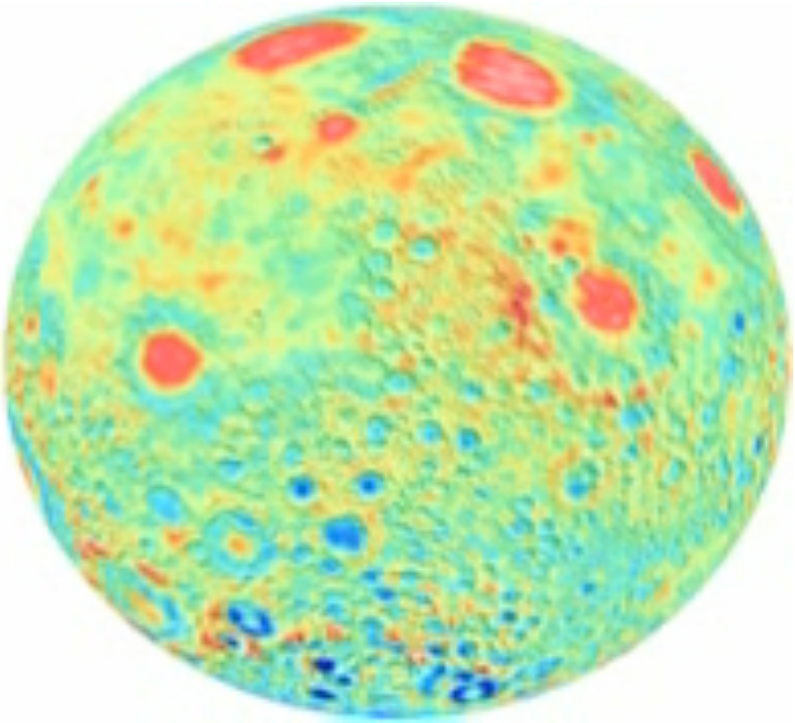
LP100K



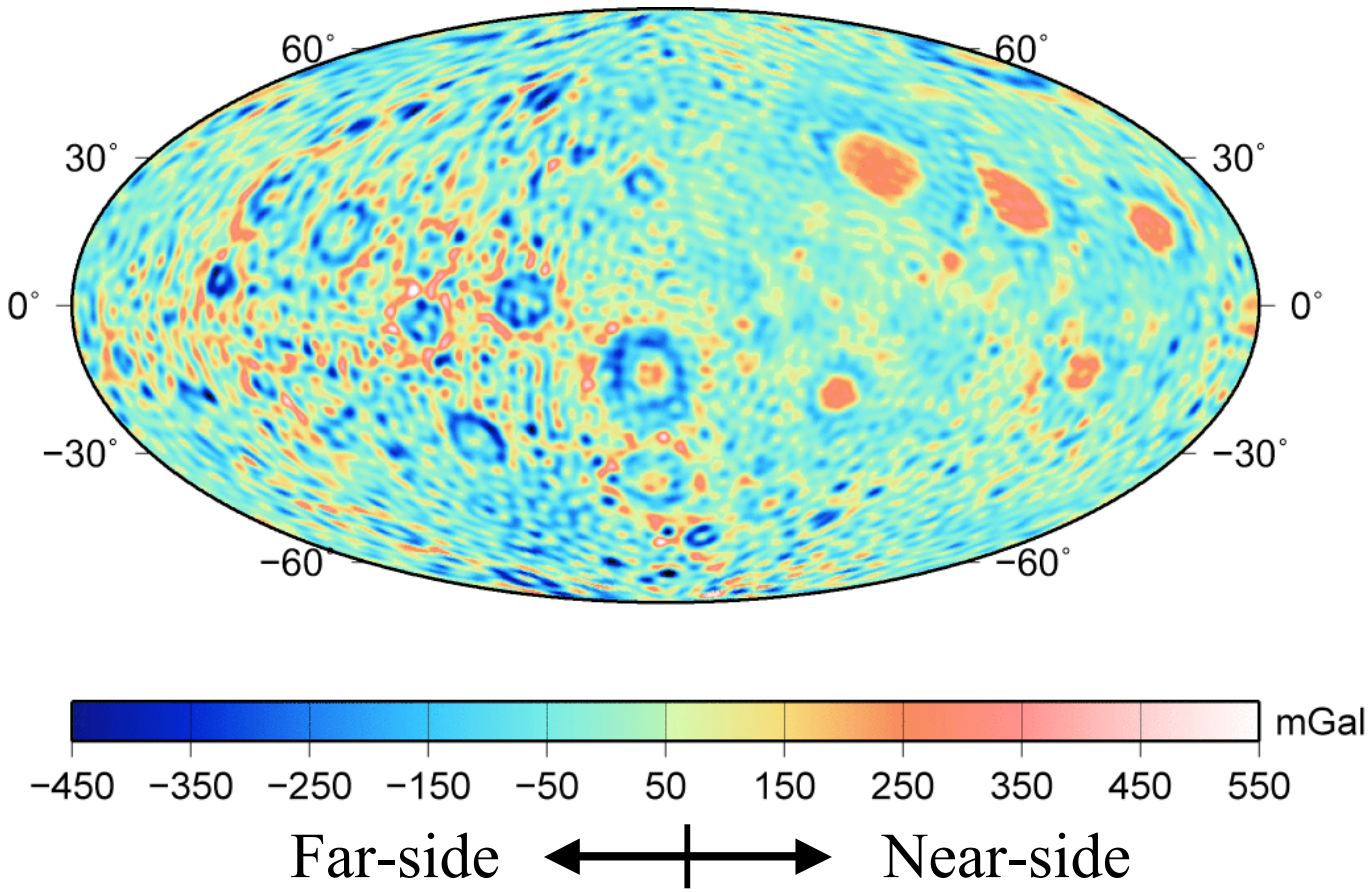
SGM100h

Topography-gravity correspondence





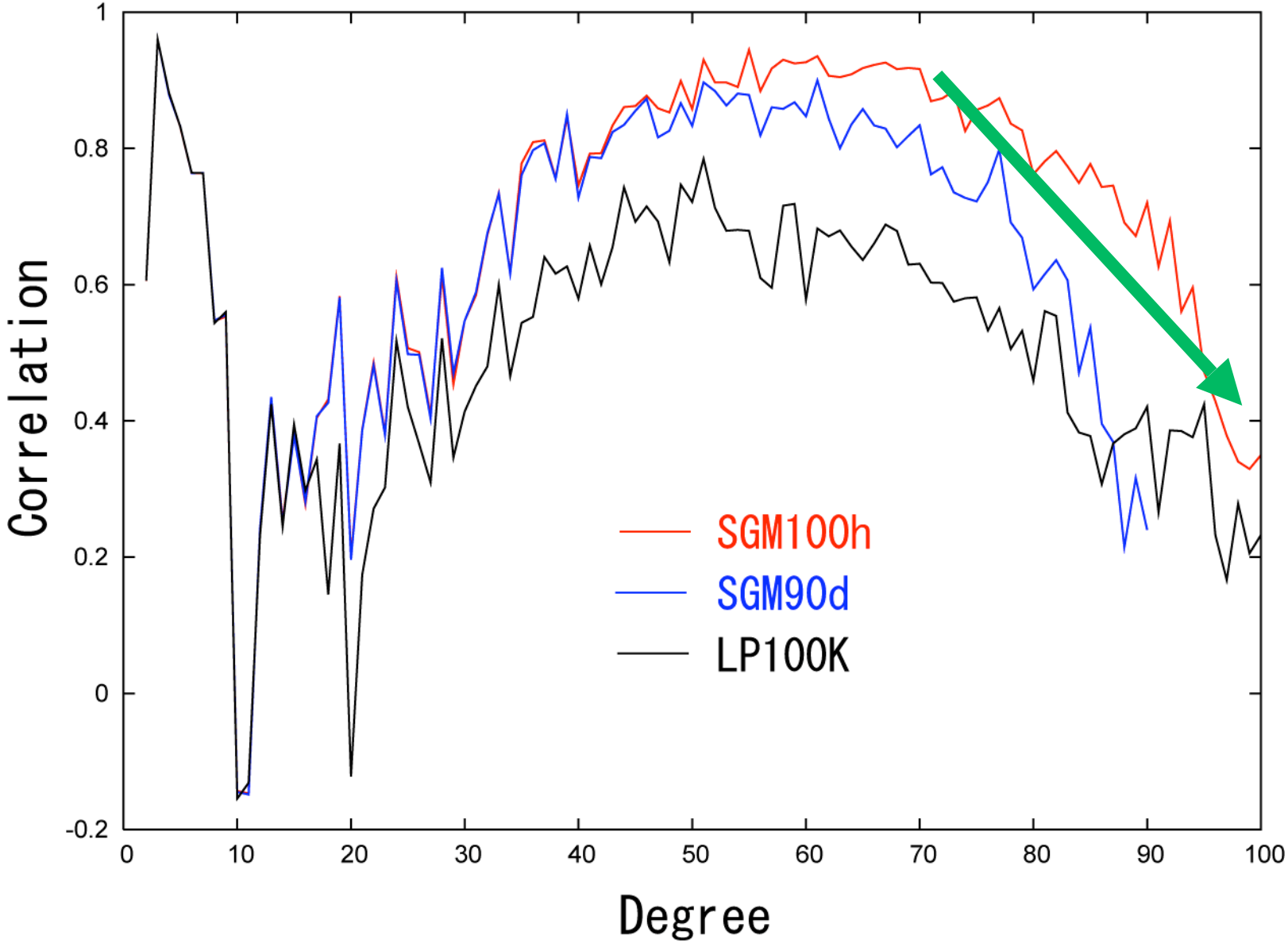
SGM90d and SGM100h

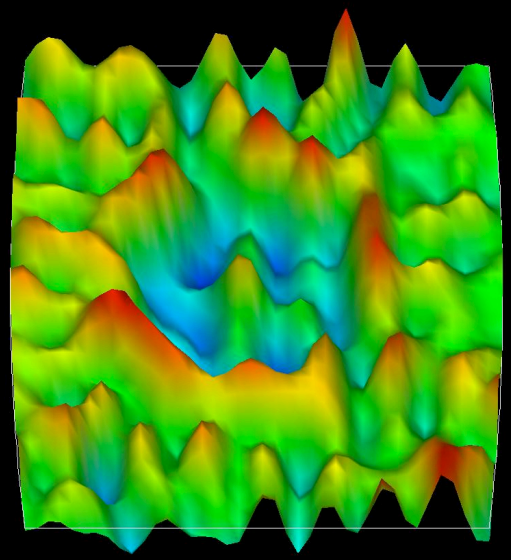


SGM90d Namiki et al. (2009)
5-month of SELENE data
plus historical data

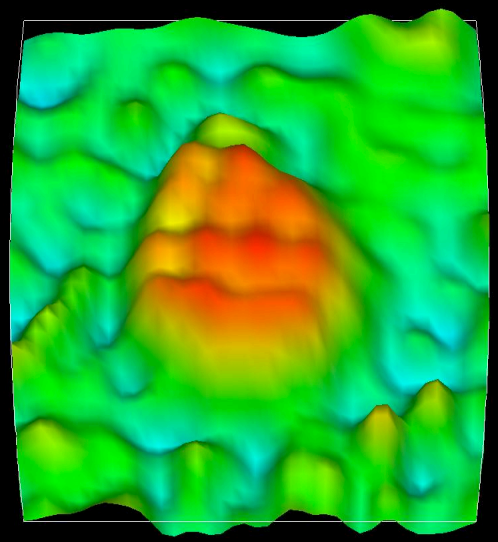
SGM100h
14-month of SELENE data
plus historical data

Gravity-topography correlation



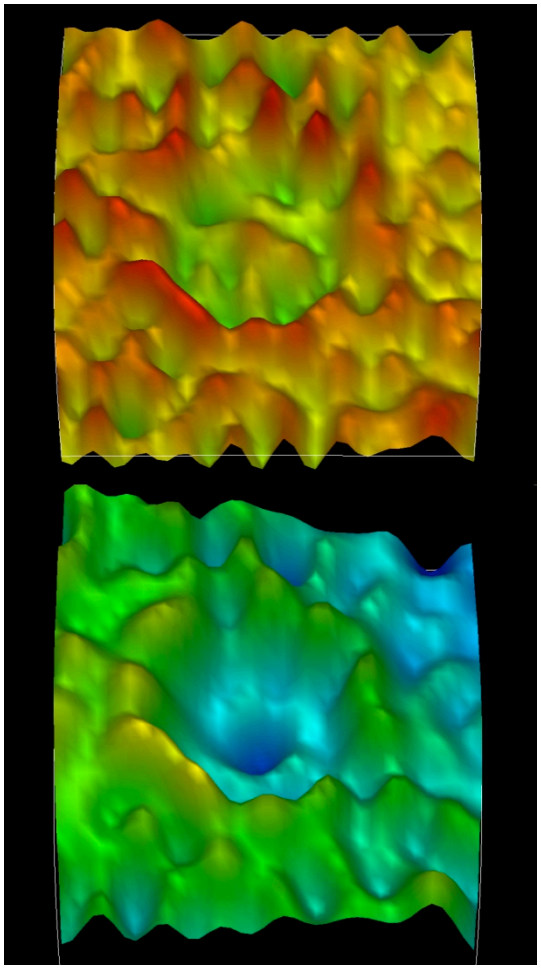


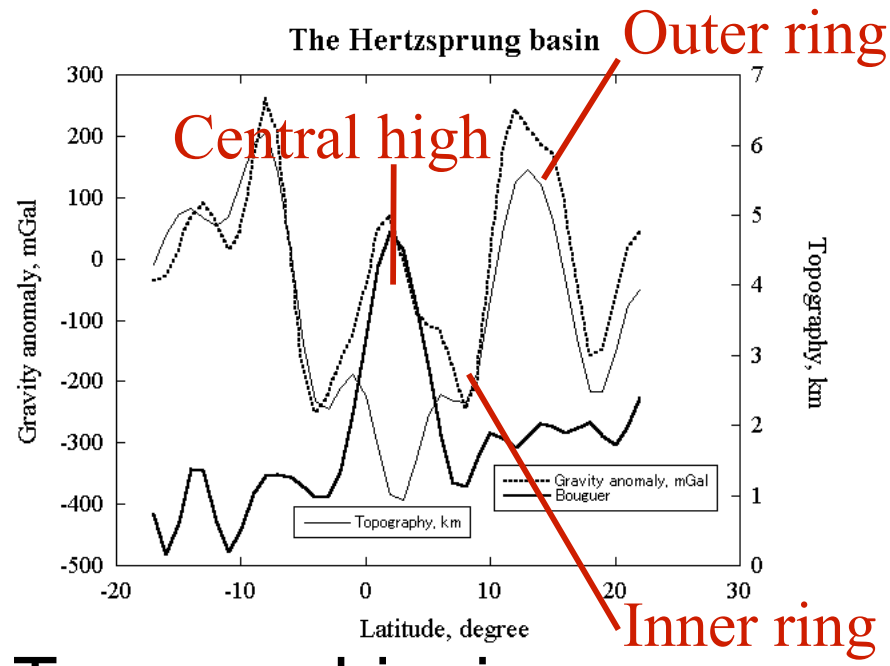
Hertzsprung (1.5° N, 128.5° W, D = 570 km)



Serenitatis basin (27° N, 19° E, D = 740 km)

Farside basins: Concentric structure





Outer ring: Topographic rim

Inner ring: Topographic depression

Central high: Density anomalies in the interior

Type I and II basins (>300km in diameter) depending on the magnitude of central high:

Namiki et al. 2009

Classification: *Major impact basins with gravity signatures*

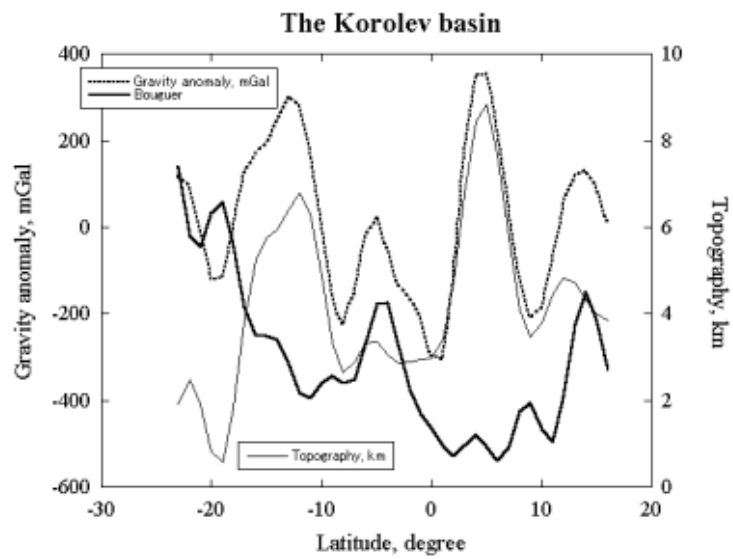
Type I basin

$(\Delta g)_{FA} \sim (\Delta g)_B$

Concentrated but weak central gravity high

Central topography +

Mare volcanism rare



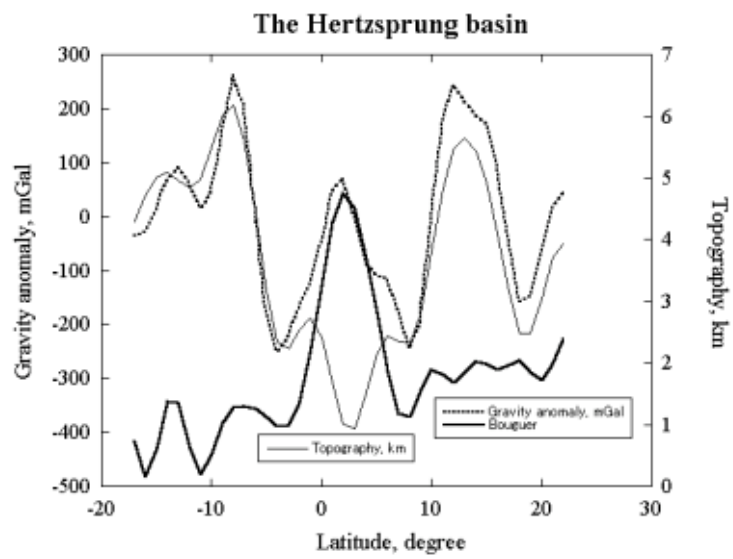
Type II basin

$(\Delta g)_{FA} \sim (50\text{-}80\ \%) \times (\Delta g)_B$

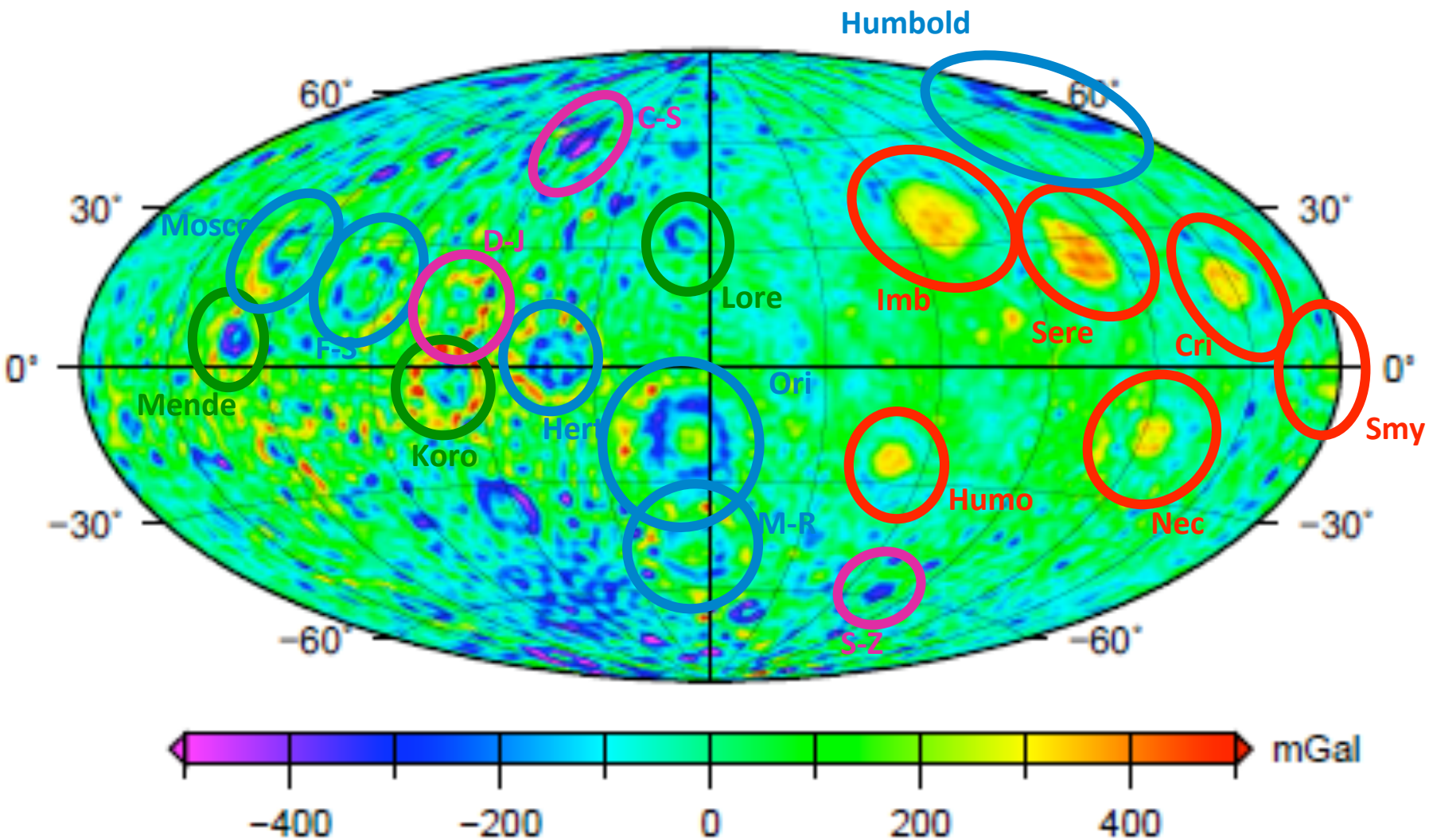
Relatively large central high

Central topography +

Associated with mare basalts

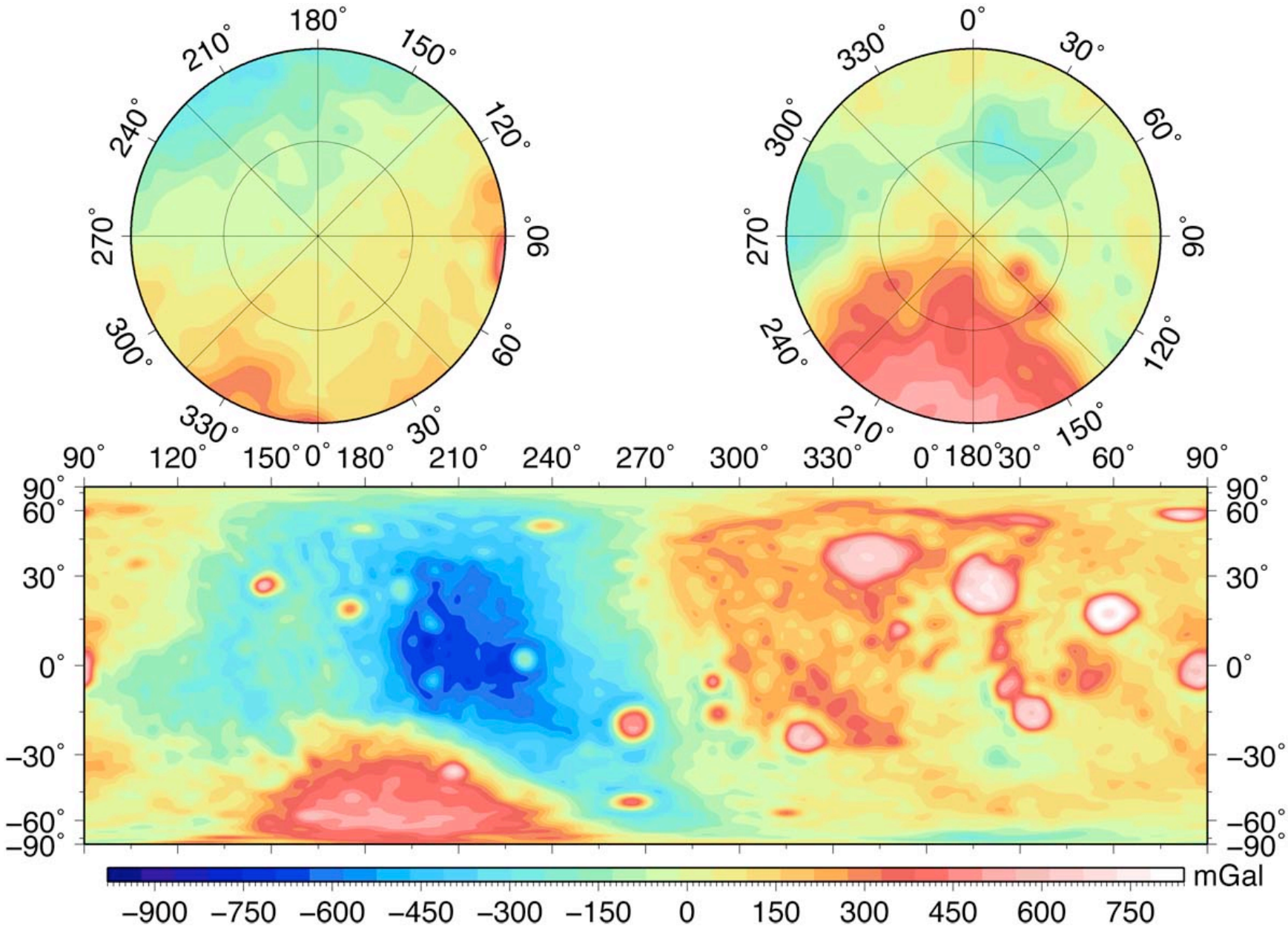


Basin classification

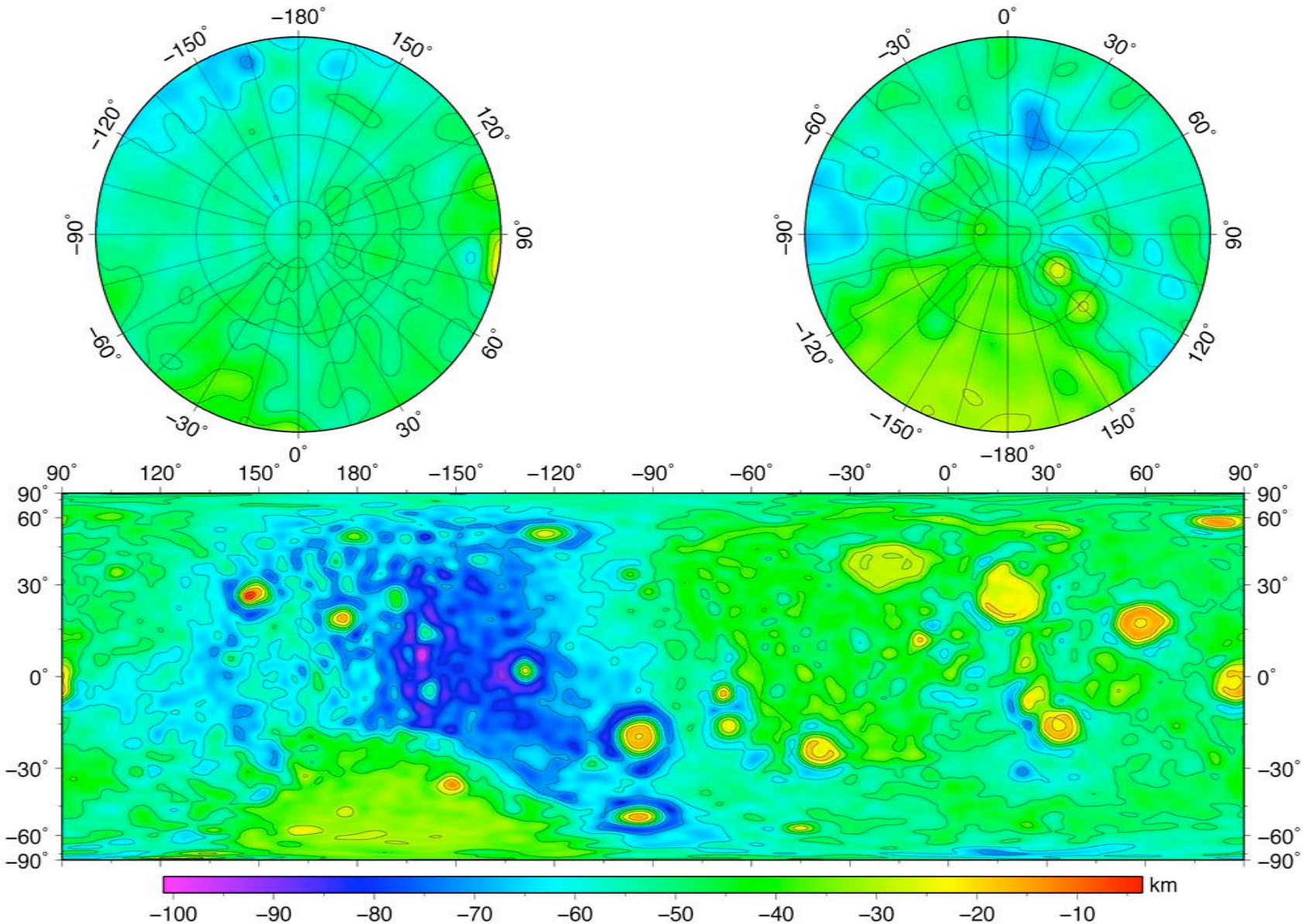


Mascon Type.1 Type.2 Un-Classified

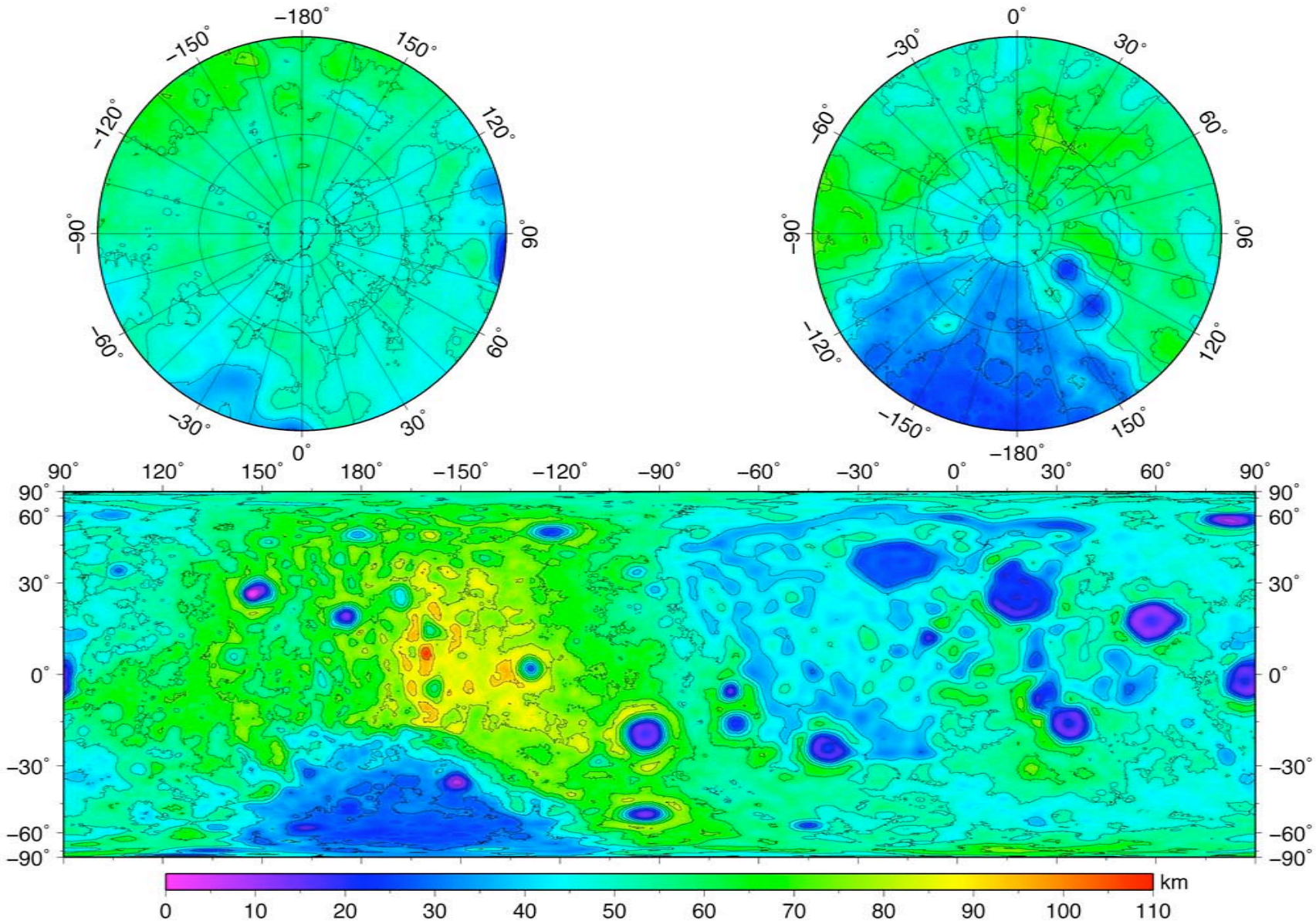
Bouguer Gravity Anomaly



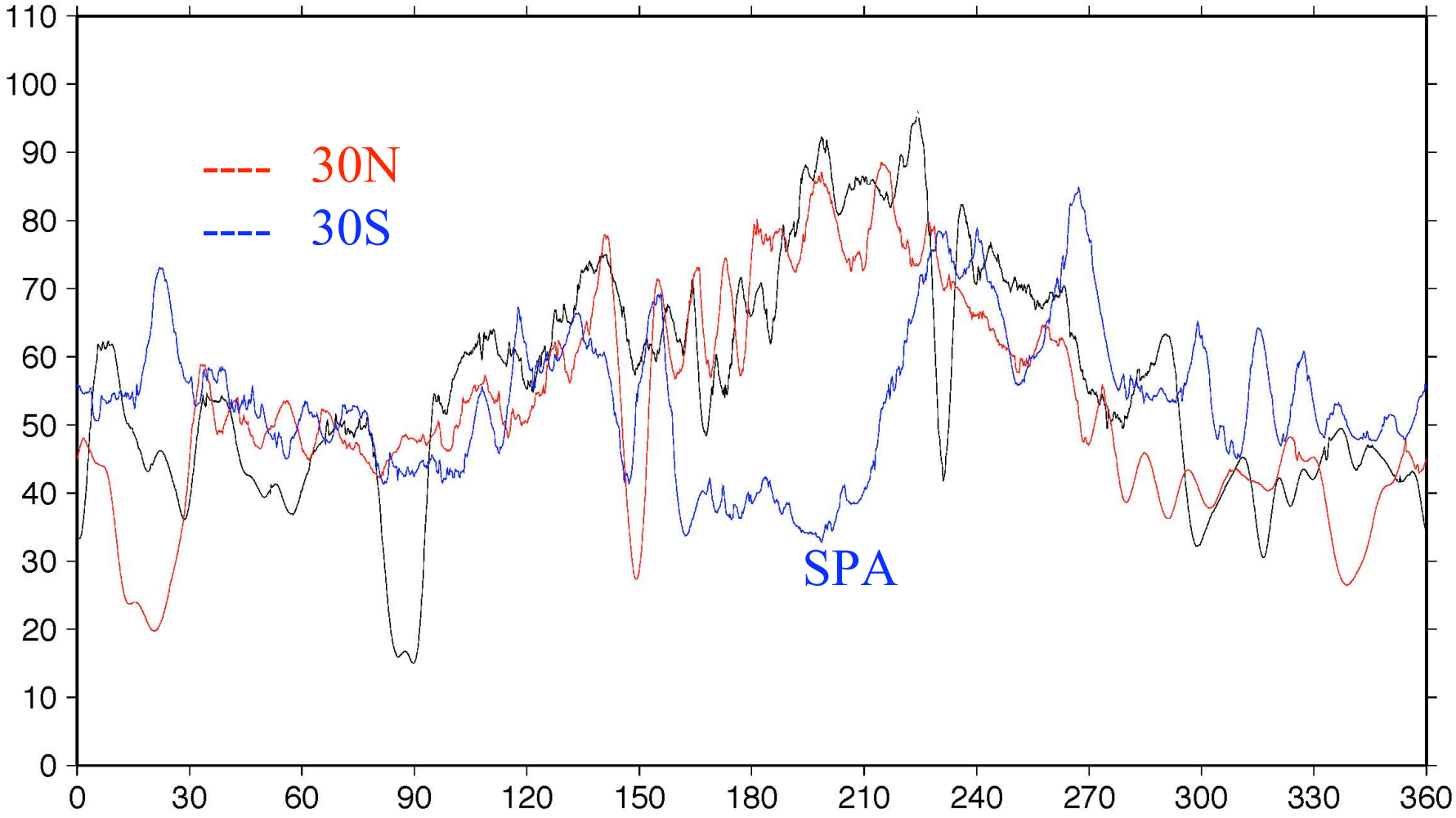
Moho Depth


−180°
−150°
150°
−120°
120°
−90°
90°
−60°
60°
−30°
30°
0°
0°
−30°
30°
−60°
60°
−90°
90°
−120°
120°
−150°
150°
−180°
90°
120°
150°
180°
−150°
−120°
−90°
−60°
−30°
0°
30°
60°
90°
90°
60°
30°
0°
−30°
−60°
−90°
km
−100
−90
−80
−70
−60
−50
−40
−30
−20
−10

Crustal Thickness

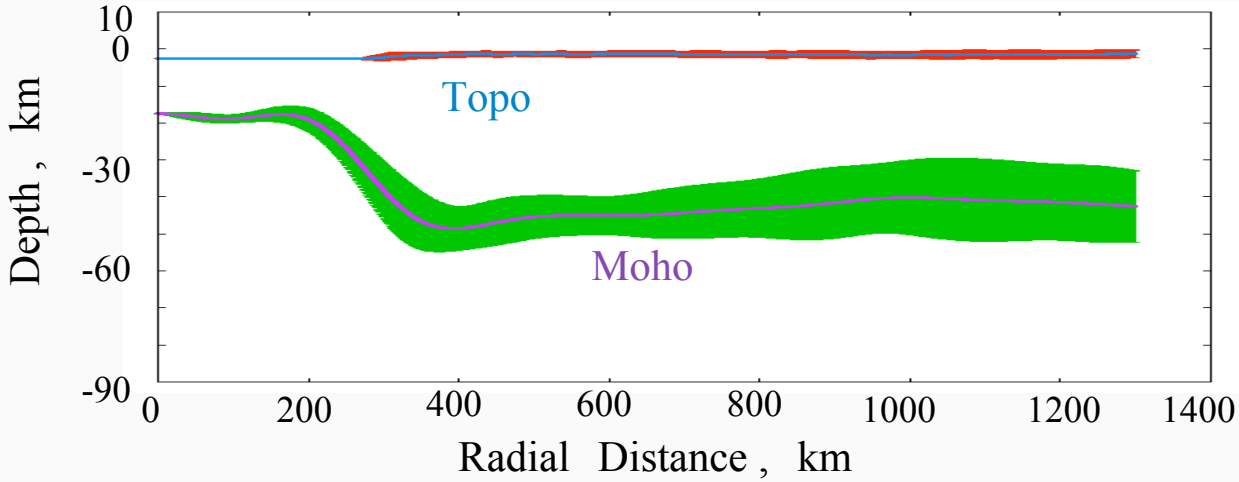


Crustal Thickness Variation



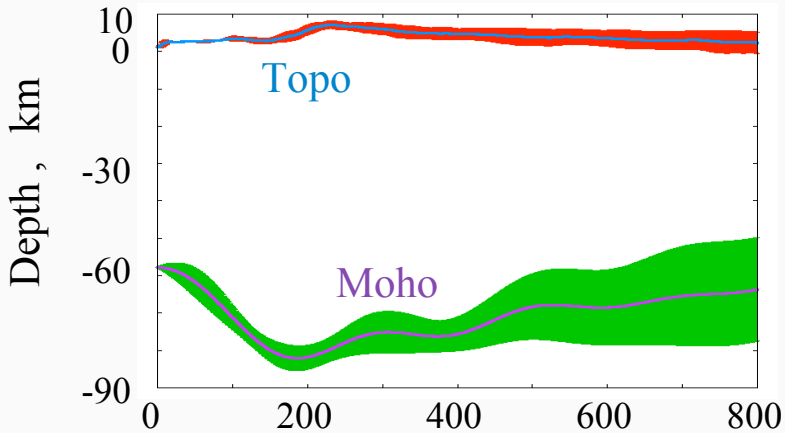
・Mascon

Serenitatis



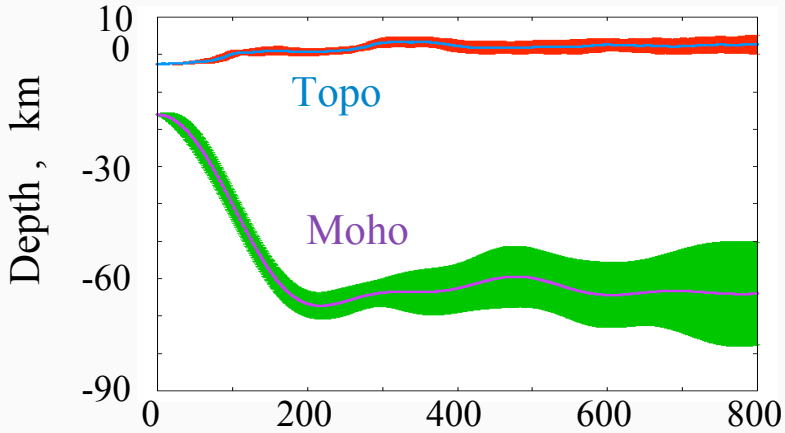
・Type.1

Korolev



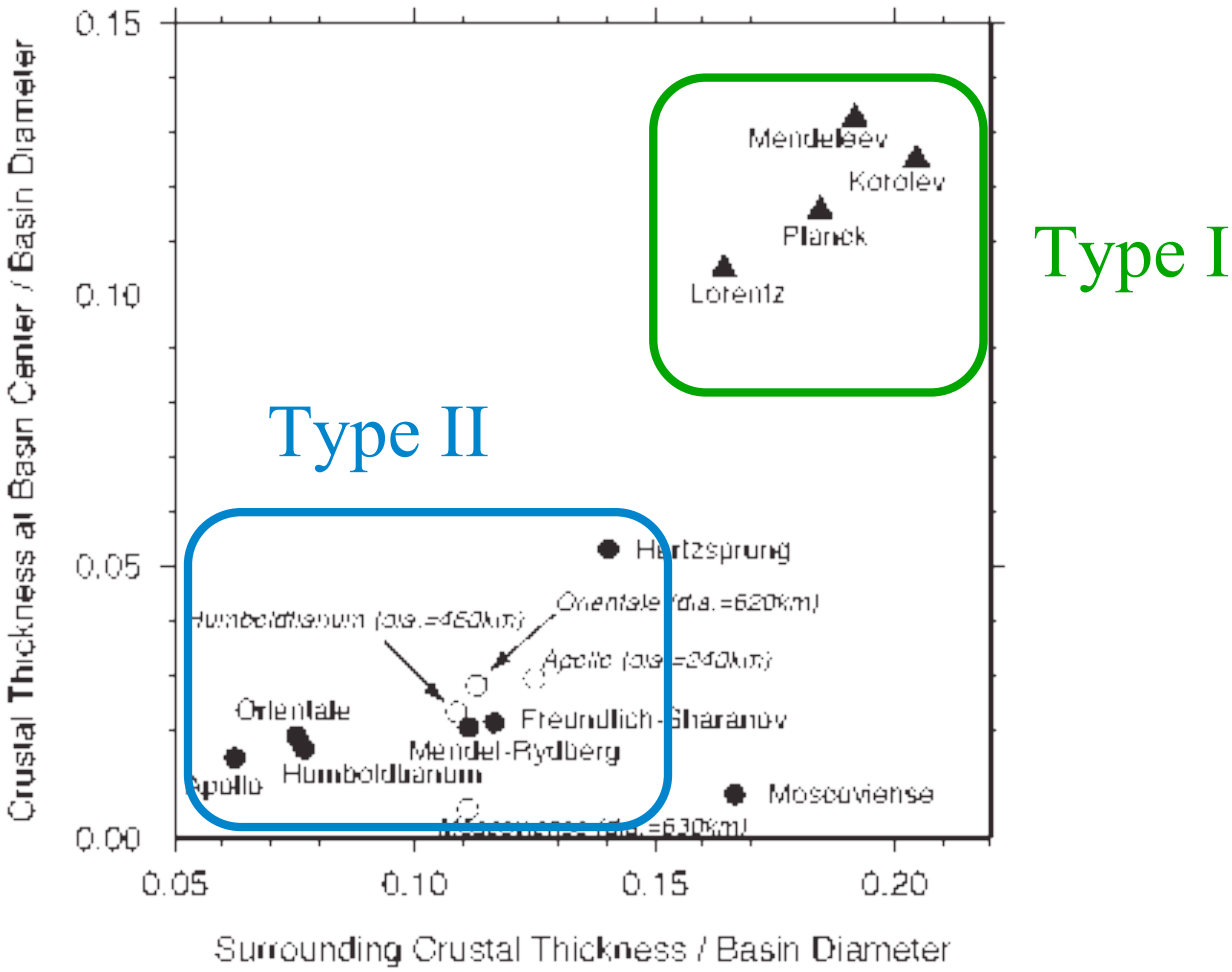
・Type.2

Freundlich-
Sharonov



Crustal Thickness vs Basin Type

Basin type I : Smaller Moho uplift at the basin center.



Summary

Lunar gravity and topography measurements by KAGUYA are ongoing successfully.

4-way Doppler tracking of KAGUYA using the relay satellite OKINA improved greatly the lunar gravity model over the far side.

Detailed topography including lunar polar regions was obtained.

Impact basins are classified into several types on the basis of gravity pattern. Far-side basin topography is not compensated. Difference of basin types could be ascribed to the difference of Moho uplift. This difference could arise from

(A) elasticity of thick crust, or

(B) rapid cooling of the far side lithosphere.

Further improvement of gravity using VLBI analysis is ongoing.

Preliminary gravity/topography data are open at JAXA /SELENE page. Detailed data will be released in November 2009.