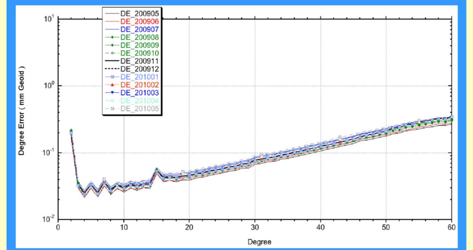
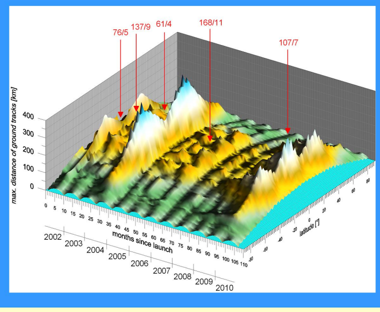
GRACE 107/7



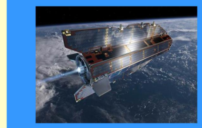
GRACE orbit resonances encountered

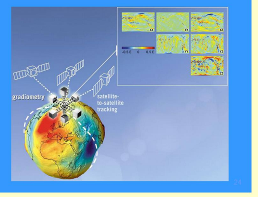


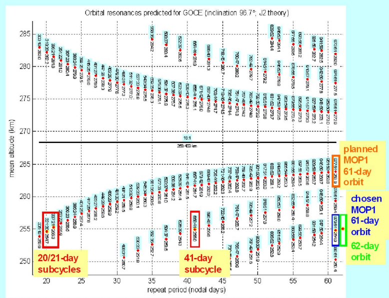
GOCE

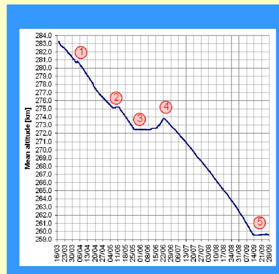
Gravity field and steady-state Ocean Circulation Explorer

First-ever satellite mission to fly a **space gradiometer**
A unique drag free system using an **electric propulsion system**
Extremely low-Earth orbit at altitude ~250 km
Aerodynamic shape 5.3 m long, 1.1 m^2 cross section, 1050 kg
Aim: measuring the Earth's gravity field with unprecedented accuracy and spatial resolution









1
Initial commissioning (17/03/2009 to 04/05/2009)

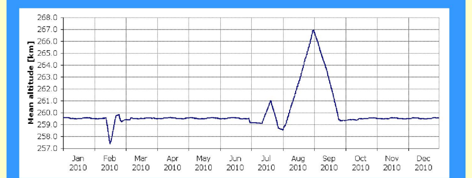
2, 3
Drag-free mode checkout (05/05/2009 to 22/06/2009). Drag-free mode was commissioned twice

4, 5
Decay to science altitude (23/06/2009 to 14/09/2009). The orbit decay was resumed (label 4) up to reaching an altitude of 259.6 km in September 2009 (label 5). From that point onwards, the altitude was maintained in drag-free mode till 2012.

Altitude of GOCE from launch on 17/03/2009

up to stop of orbit decay on 14/09/2009

979:61



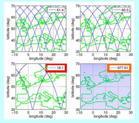
Altitude of GOCE in 2010, showing interruptions of drag-free modeat 260km in Feb and July–Sept.

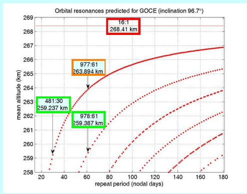
Global gravity field models from GOCE and resonances

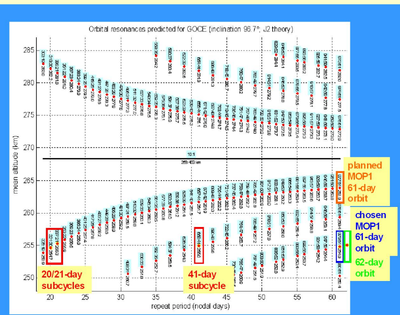
- Resolution of 100 km › minimum repeat period of 2 months

Strong 16:1 resonance must be avoided for the measurement phases

We studied two candidate 61-day orbits providing dense enough sampling:
- higher orbit with no subcycles
- lower orbit with 30-day subcycle

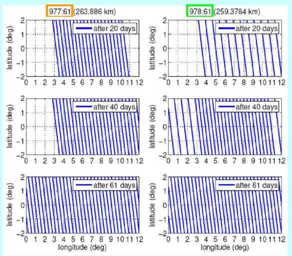


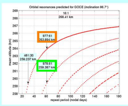




Temporal evolution of an orbit – with/without a subcycle

- Repeat orbit with no subcycles › gradually filling up two large equatorial gaps
- Repeat orbit with a subcycle › groundtracks laid down in two (or more) almost homogeneous grids



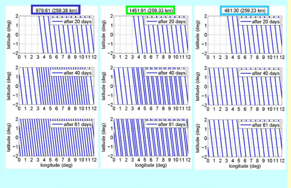


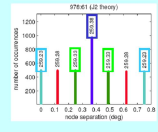
Small variations in altitude of repeat orbits

Exact 61-day repeat orbit
- mean altitude 259.38 km
- one peak in histogram

Height lower by 50 m
- grid not regular after 61 days
- in fact, 91-day repeat

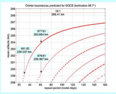
30-day subcycle
- mean height lower by 150 m
- inacceptable for GOCE

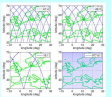


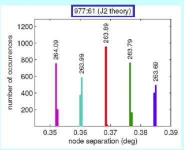


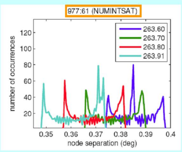
Analytical vs. numerical modelling

- So far, graphs based on simple theory with only the zonal term J2 (flattening of Earth)
- What happens when all other orbital perturbations (geopotential, lunisolar, tides, radiation, …) are added?
  - ➢Peaks in histograms widened
  - ➢Repeat character is kept
  - ➢Earth coverage graphs almost the same (0.02° - 2 km)







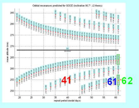


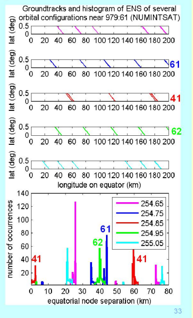
Orbits near the MOP1 61-day orbit of GOCE

- Equator with groundtracks after 65 days
- Different mean altitudes

Repeat orbits:
- 61-day (selected for MOP1)
- 41-day subcycle

- 62-day orbit compared with 61-day
  - ➢has *more regular* groundtrack grid
  - ➢is only by *200 m higher*





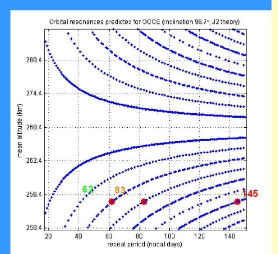
The 145-day orbit with 62/83 day subcycles

Suggested repeat orbit for 2011 2327:145
node spacing ? 17.2 km
Nearest repeat orbits
- 62-day, lower by 30 m
- 83-day, higher by 23 m

Ion thruster performance ±5 m
145-day repeat is a good choice
› node spacing at least
➢40.3 km for 62-day repeat
➢30.1 km for 83-day repeat

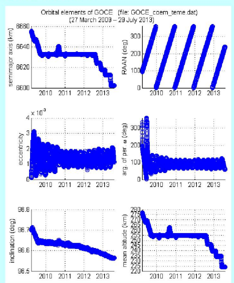
Resonant orbits ordered by height

β	?	h (km)
1653	103	255,062
995	62	255,105
2327	145	255,135
1332	83	255,158
1669	104	255,19
2006	125	255,211
2343	146	255,226



GOCE's "second mission"

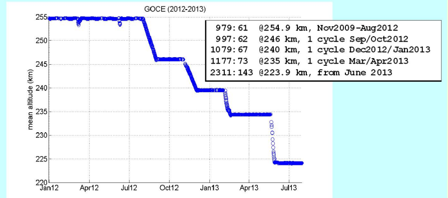
- ESA's Earth Scientific Advisory Committee recommended lowering the orbit to 235 km starting in August 2012.
- Lowering the orbit increases the accuracy and resolution of GOCE's measurements, improving the quality of the gravity model.
- The expected increase in data quality is so high that scientists are calling it GOCE's 'second mission.'



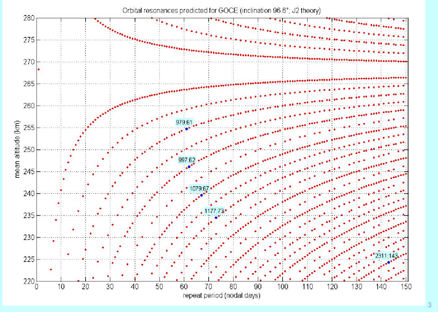
(http://www.esa.int/Our_Activities/Observing_the_Earth/GOCE_s_second_mission_improving_gravity_map)

Fine orbit tuning of GOCE

a) we started from the >60d requirement and with the need to understand the GOCE orbit control performance
b) gradually we got to know VERY WELL our baby and could control very finely
c) therefore focus was given mainly on flying as low as possible by more pro-active risk management and by introducing tighter monitoring of the satellites

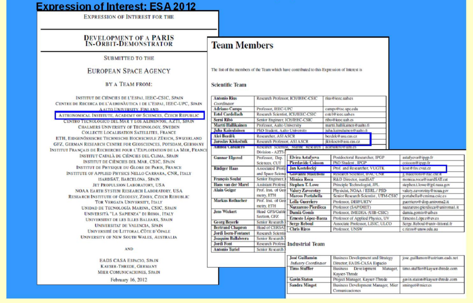


Resonance diagram for GOCE



Expression of Interest, submitted to ESA in 2012: for development of a PARIS in-orbit-demonstrator

- **PARIS = Passive Reflectometry and Interferometry System, Martin-Neira 1993, Expression of Interest: ESA 2012**


EXPRESSION OF INTEREST FOR THE

DEVELOPMENT OF A PARIS IN-ORBIT-DEMONSTRATOR

SUBMITTED TO THE

EUROPEAN SPACE AGENCY

BY A TEAM FROM:

INSTITUT DE CIÈNCIES DE L'ESPAI, IEEC-CSIC, SPAIN
CENTRE DE RECERCA DE L'AERONÀUTICA I DE L'ESPAI, IEEC-UPC, SPAIN
AALTO UNIVERSITY, FINLAND
ASTRONOMICAL INSTITUTE, ACADEMY OF SCIENCES, CZECH REPUBLIC
CENTRO TECNOLÓGICO DEL MAR Y LOS ALIMENTOS, AZTI, SPAIN
CHALMERS UNIVERSITY OF TECHNOLOGY, SWEDEN
COLLECTE LOCALISATION SATELLITES, FRANCE
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UNIVERSITÉ DU LITTORAL CÔTE D'OPALE
UNIVERSITY OF NEW SOUTH WALES, AUSTRALIA

AND

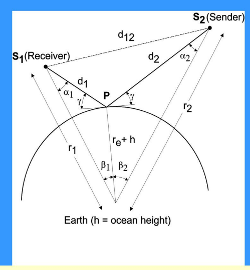
EADS CASA ESPACIO, SPAIN
KAYSER-THREDE, GERMANY
MIER COMUNICACIONES, SPAIN
February 16, 2012

Team Members

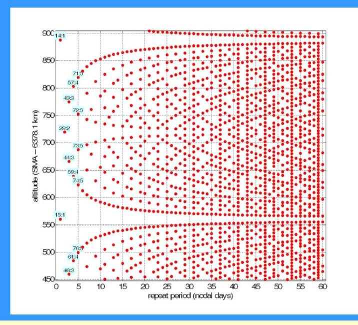
Scientific Team

Industrial Team

PARIS (PAssive Reflectometry and Interferometry System), suggested and also patented by M. Martín-Neira (1993)



GNSS-R ESA project



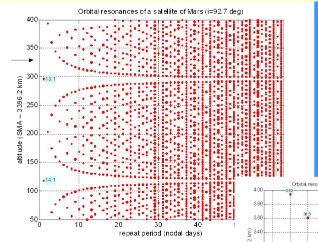
PLANETS

On the possibilities of the orbit tuning for planetary mission

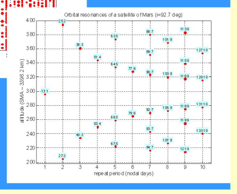
Basic dynamic parameters of the Earth and other bodies of the solar system

body	*GM* [km^3s^{-2}]	J_2 [10^{-6}]	*R* [m]	*?* [rev/day]
Earth	398600.44	1082.627	6378137	1.00274
Moon	4902.80	203.428	1738140	0.03660
Mercury	22032.24	60	2439700	0.01705
Venus	324858.36	5.97	6051800	-0.00411
Mars	42828.37	1959.2	3396190	0.97470

Klokočník J, Bezděk A, Kostelecký J, Sebera J, 2010:
Orbit tuning of planetary orbiters for accuracy gain in gravity-field mapping.
Journal of guidance, control, and dynamics **33**(3), 853–861. http://dx.doi.org/10.2514/1.46223

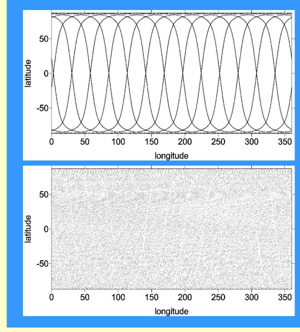


MARS



Lmax < ß/2!

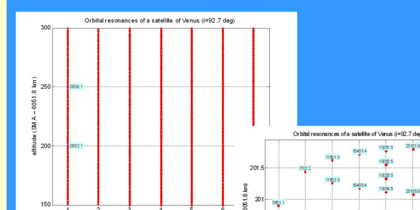
MARS

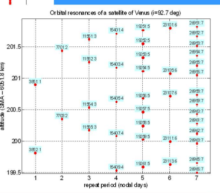


Ground tracks for a Mars orbiter at the 13:1 and 188:15

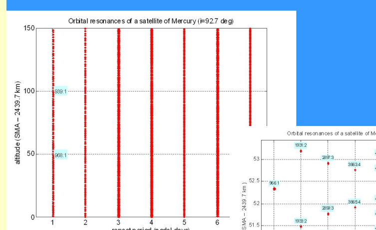
density *D* at 13:1 is 1640 km,
D at 188:15 is ~ 110 km

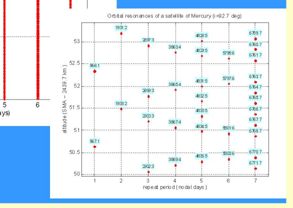
VENUS





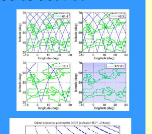
MERCURY

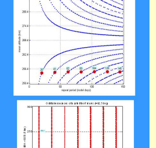


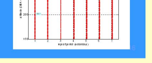


Rationale behind fine orbit tuning & conclusions

- Without "good" coverage even the most sophisticated space instrument would not produce "the best attainable" geopotential coefficients or other data
- CHAMP and GRACE experience › ESA sought for optimally dense and regular ground tracks grids
- Direct relationship between the density of satellite ground tracks and accuracy of the gravity field parameters derived, inherent presence of orbit resonances, intentional orbit tuning as a tool to maximize accuracy gain in the gravity field mapping
- Special situation of GOCE
- A small shift in altitude may considerably affect the full utilization of the accuracy of the instrument
- Heights of highlighted orbits: only ±180 m, ground track density is extremely different
- Highlighted orbits also differ in regularity of their coverage pattern
- For planetary orbiters: problems for Mars
- (not for slowly rotating Venus, Mercury or the Moon,
- ***Lmax < < ß.***)







More information: www.asu.cas.cz/~jklokocn, ~bezdek

Acknowledgements

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Contributions of Aleš Bezděk, Jan Kostelecký, Robert H. Gooding, Rune Floberghagen and Manuel Martín-Neira are highly acknowledged.

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Klokočník J, Bezděk A, Kostelecký J, Sebera J, 2010. Orbit tuning of planetary orbiters for accuracy gain in gravity-field mapping. Journal of guidance, control, and dynamics 33(3), 853–861. http://dx.doi.org/10.2514/1.46223

Klokočník J, Bezděk A, Kostelecký J, 2012. GNSS-R concept extended by a fine orbit tuning. Advances in Space Research 49, 957–965. http://dx.doi.org/10.1016/j.asr.2011.12.008

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