From grass roots to galaxies: IP research at Tampere UT

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Research areas, plans

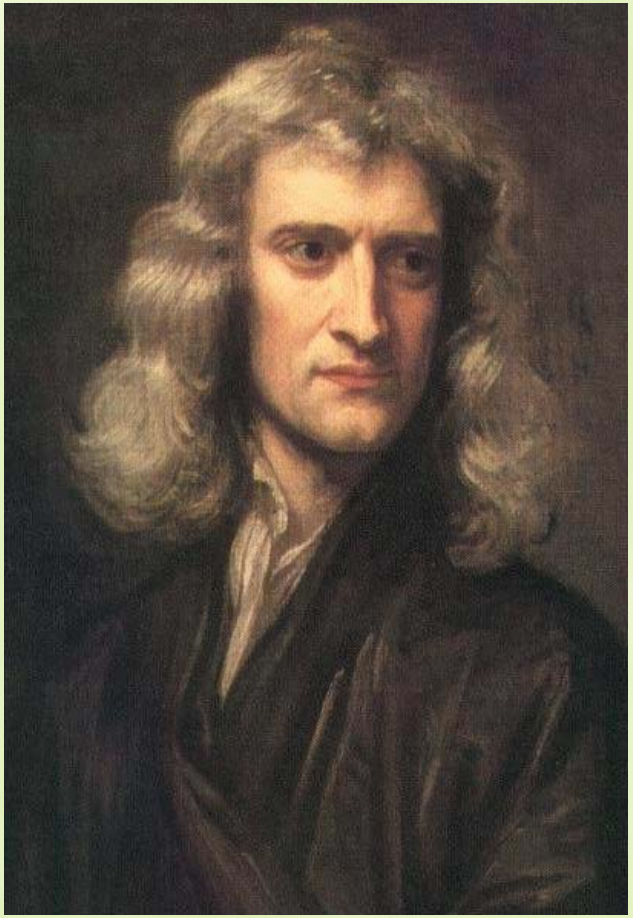
- Space research, dynamical systems, climate/ecological studies (carbon cycle+biomass), remote sensing (laser scanning, radar), biomedical imaging
- Generalized projection operators, phase-space tomography, Poincare inverse problem of dynamics, sparse stochastic tomography, optimal combination of multiple data modes (maximum compatibility estimate, MCE), information content of data
- TUT students from various fields, strongly application/hands-on oriented

Galaxies and dark matter

- We live at the edge of the disk
- Dust obscures a lot
- But high density of material: lots of data
- How is *dark matter* distributed? What is it made of?
- Thus: what potential field (=> distribution of matter) holds the system together?

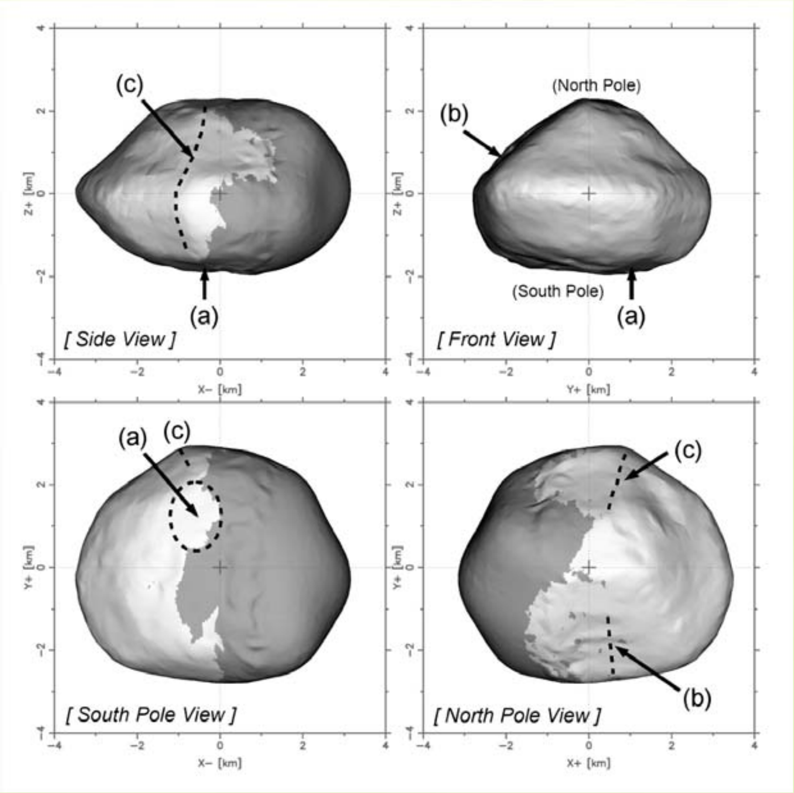
Generalization of Newton's inverse problem

- $F \propto 1/r^2$ => elliptic orbit (conical sections)
- Inverse problem: elliptic orbit => $1/r^2$ (when motion around foci)
- How to generalize this to N>>2 bodies (e.g. positions and velocities of a billion stars)?
- Tomography in six dimensions!
- Poincare IP of dynamics: torus construction



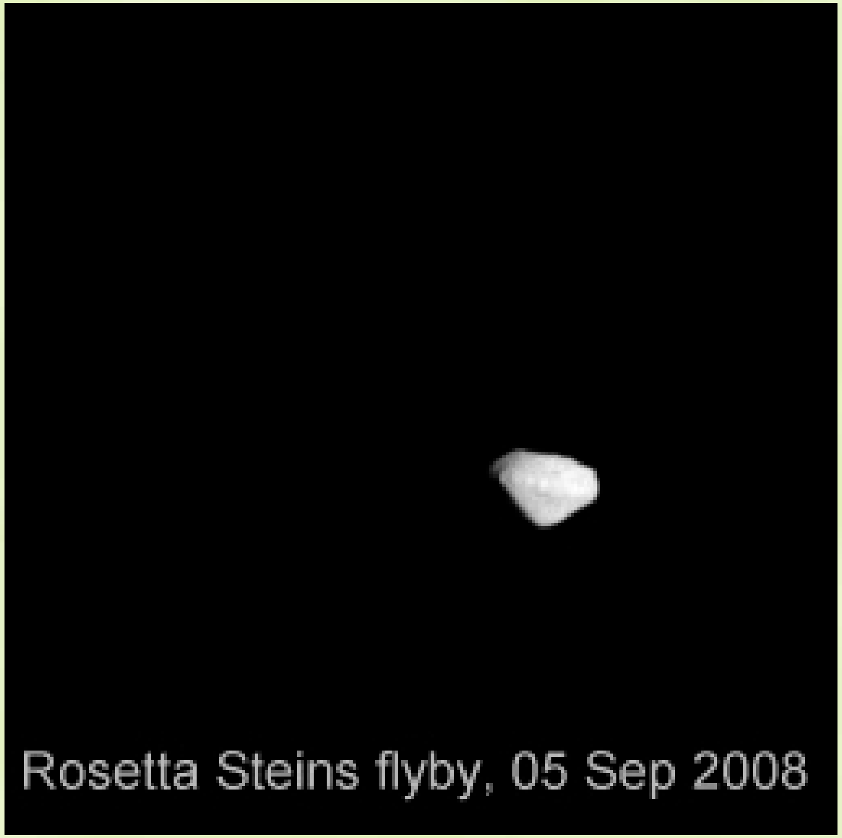
Space research: how to see the dark side

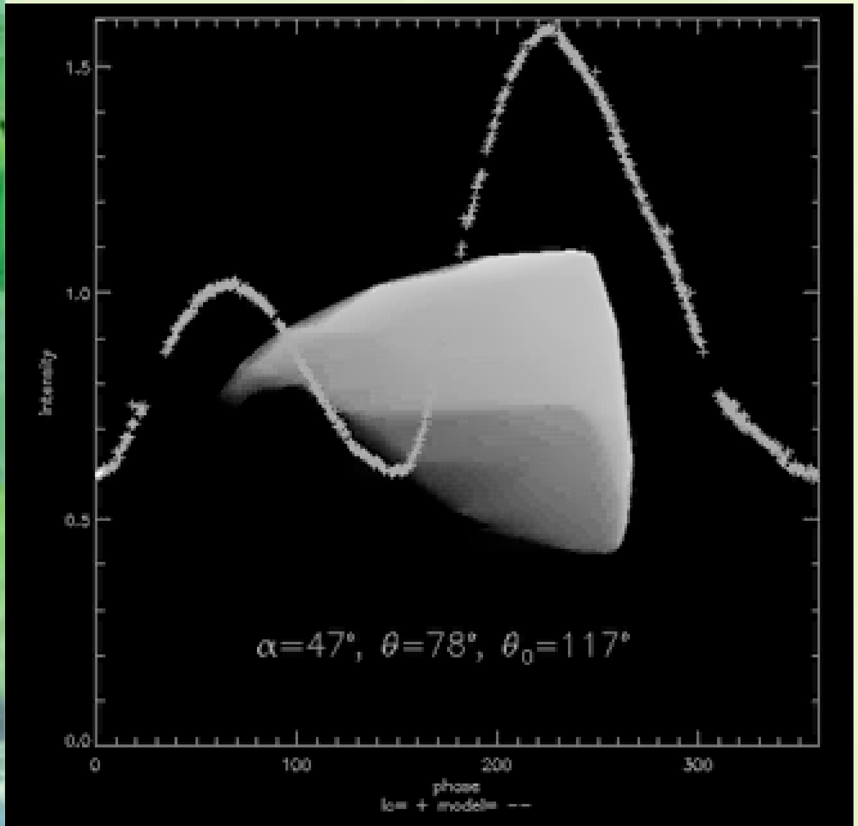
- ESA's Rosetta probe flew fast by the asteroid Steins and saw only one side (and the hi-res camera was lost)
- We reconstructed the other half from brightness data
- Stable solution: strong constraints by images
- YORP effect visible, cf. Kaasalainen et al. 2007, Nature

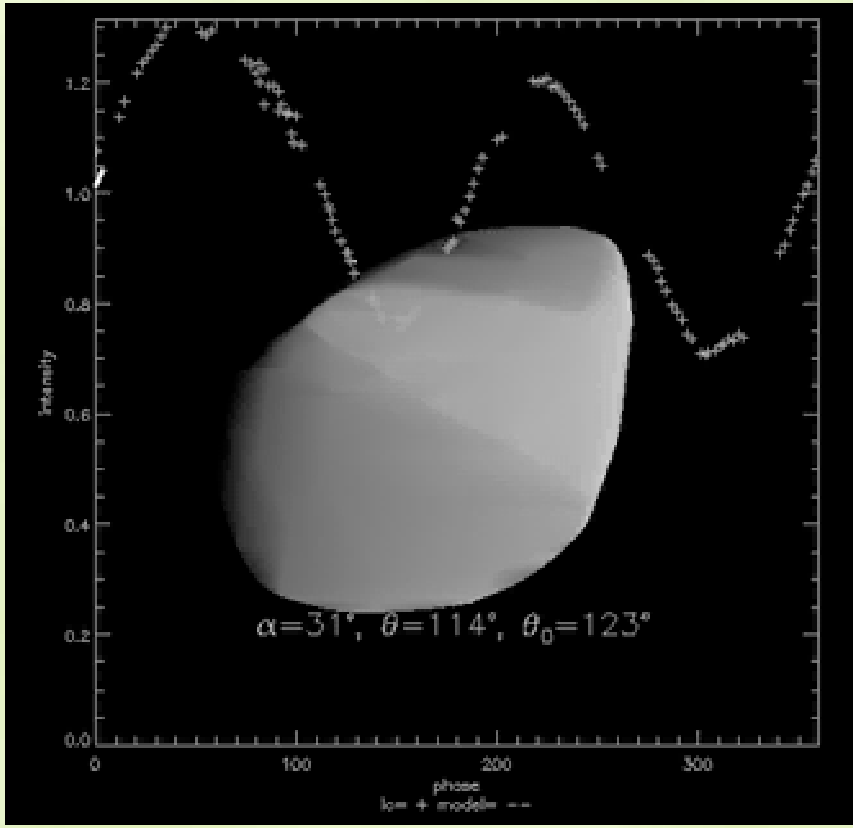


Rosetta: Steins flyby

- Flyby lasted only 7 minutes
- Closest encounter 800 km, target size 5 km
- Speed w.r.t. target 8.6 km/s =31000 km/h
- Dark side reconstruction cost ~0 €, gave significant added value to a project of 700 million €
- Keller et al., Science 2010 (Osiris team, ~50 co-authors)





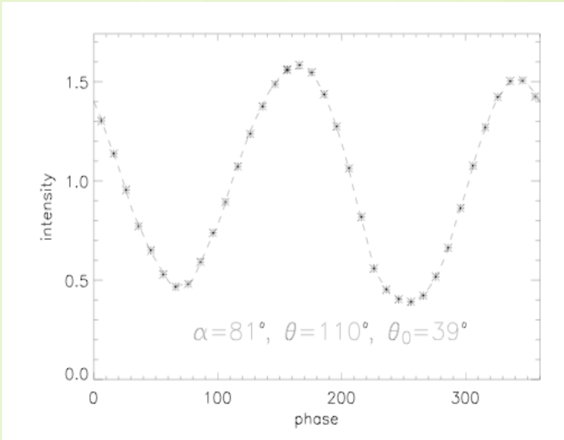


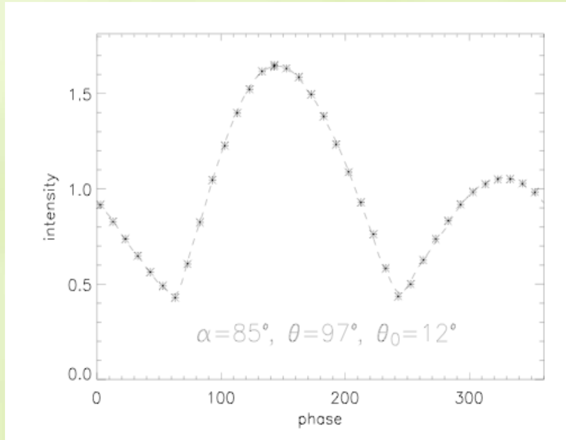
- Shape/spin reconstruction methods now standard software (web+Windows) in international use; web-based database (maintained by J. Durech, Charles Univ., Prague)
- Now combining multiple data modalities (e.g. photometry and adaptive optics)

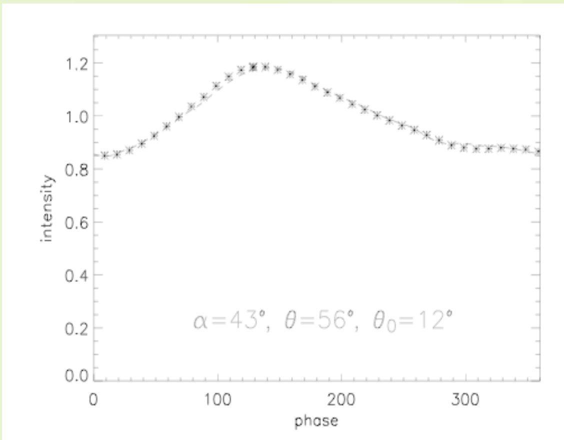
Fundamental theorems

- Uniqueness theorem: With $S^2 x S^2$ data, i.e., outside Russell degeneracy, there is a unique convex shape solution (corollary from Gaussian image uniqueness theorem and Minkowski-Nirenberg shape theorem)
- Stability theorem: the map LC->shape is continuous in usual topologies (the inverse problem is well-posed in the sense of Tikhonov) => *Minkowski stability*

Laboratory ground truth







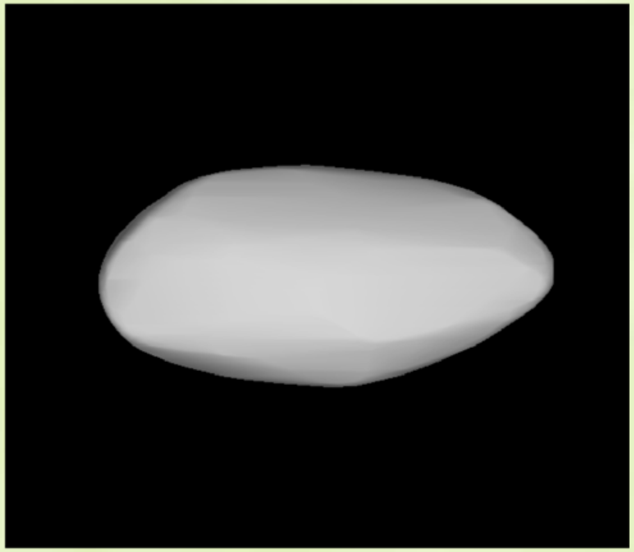


Fig. 5. Views of the target from the same viewpoints as the model images (Fig. 4).

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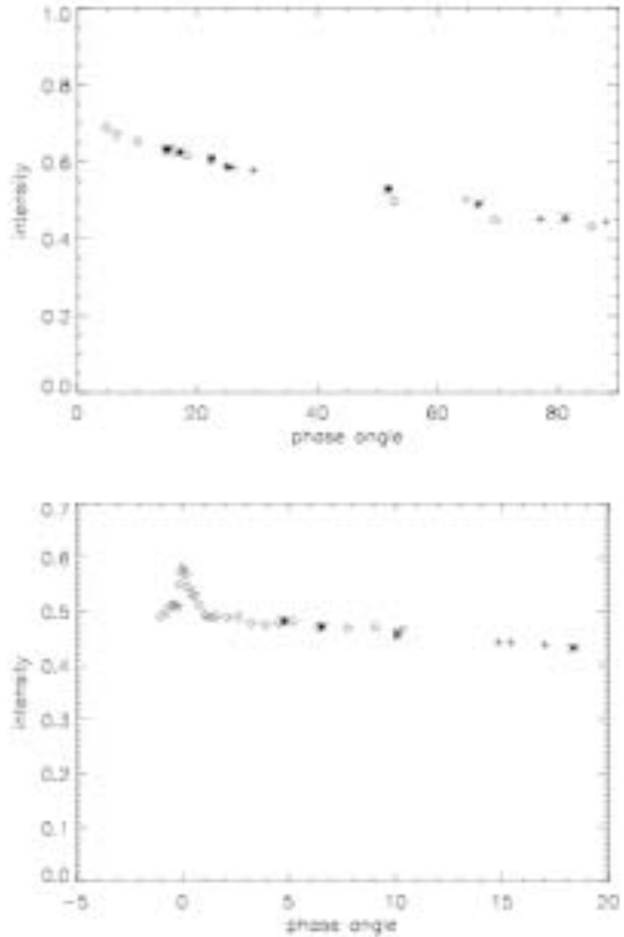


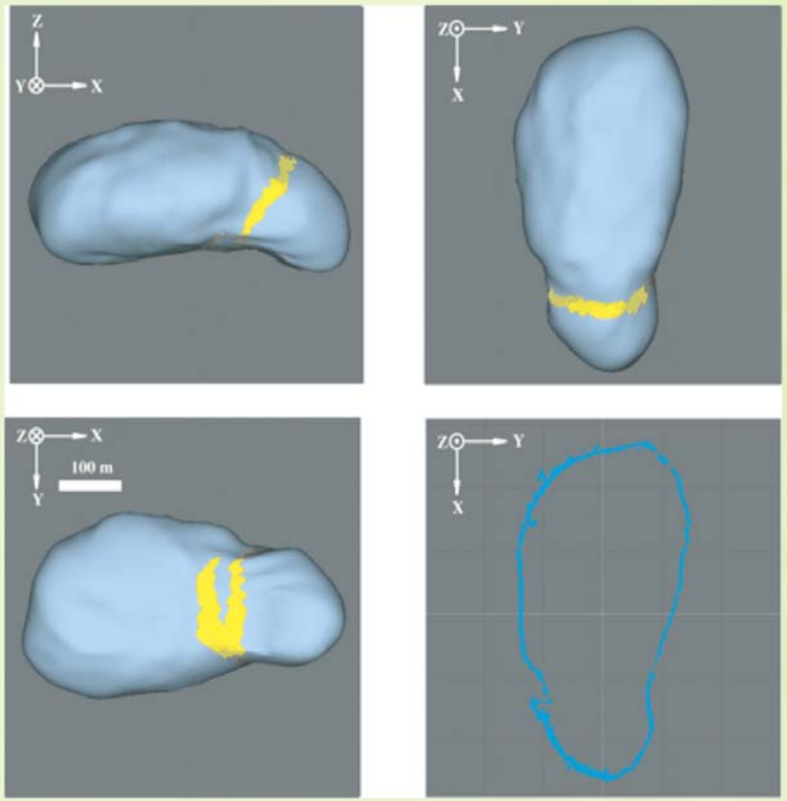
Fig. 7. a) The measured BRDFs at different values of μ, at 633 nm. b) Phase curves at 633 nm combined (by normalizing at 6.5°) from BRDF measurements (asterisk; the plot is made at $\mu = 60°$) and small-angle laser measurement (diamond).

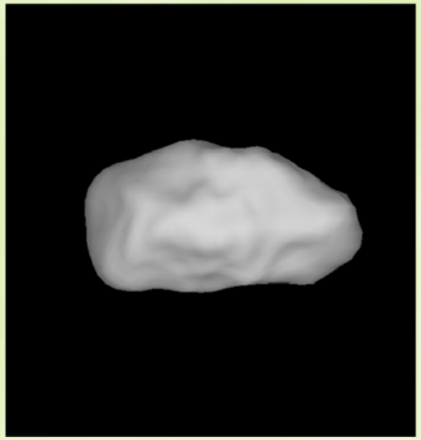
Radars

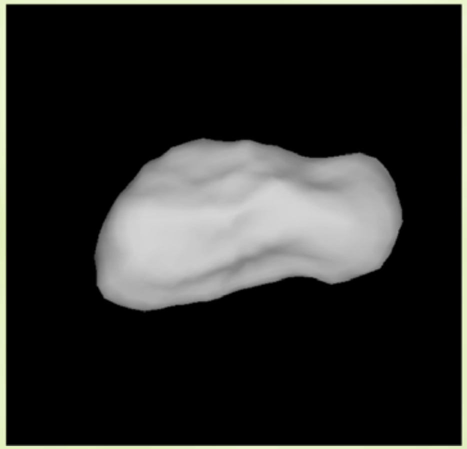
- Sodankylä EISCAT 32 m
- Arecibo 300 m
- Ionosphere, space debris, moon, asteroids
- New EISCAT in planning
- Analysis in time/amplitude domain (vs. frequency/power)

Caveat emptor: ground truth vs. basic radar model

Proper inverse modelling and model error analysis needed!







Carbon cycle, biomass estimation+carbon footprint

- Collaboration with environmental and geodetic institutes
- Model selection problem, design of experiments
- Biomass estimation, disintegration profiles
- Laser scanning technologies, mobile platforms?