SKA and its pathfinders for planetary science and exploration

Leonid Gurvits
JIVE, Dwingeloo, The Netherlands

with contributions by
S.V. Pogrebenko, G. Cimò, P.A. Fridman
and PRIDE collaboration

SKADS conference, Limelette, 6 Nov 2009
Spacecraft as a celestial radio source

• Spacecraft tend to be radio loud… actually?
  • Transmitter power 1 W
  • Distance 5 AU (Jupiter)
  • On-board antenna gain 3 dB
  • Bandwidth 100 kHz

Flux density ≈ 0.5 mJy

• Operate at frequencies we love (or hate):
  UHF (400 and 800 MHz), S (2.3 GHz), X (8.4 GHz), Ka (32 GHz)

• Estimates of state-vectors of spacecraft:
  • Need for “higher-than-standard” accuracy in special cases
    • Geodynamics and planetology
    • Trajectory measurements in close vicinity of Solar System bodies (e.g. landings)
    • Fundamental physics
    • Space-borne astrometry missions (e.g. GAIA)

• Need for “eavesdropping” (sometimes, in desperation…)
Huygens VLBI heritage: 20 photons/dish/s

- Ad hoc use of the Huygens “uplink” carrier signal at 2040 MHz
- Utilised 17 Earth-based radio telescopes
- Non-optimal parameters of the experiment (not planned originally)
- Achieved 1 km accuracy of Probe’s descent trajectory determination
- Assisted in achieving one of main science goals of the mission – vertical wind profile

Titan, 14 January 2005

Titan atmosphere turbulence signature

3D Huygens descent trajectory

σ_x = 1 km
σ_v = 3 cm/s
Generic PRIDE configuration

Planetary Radio Interferometry and Doppler Experiment

Earth

VLBI Network and Two-way tracking stations

Background radio sources

Orbiter

Planet-target

Micro Lander

Balloon

PRIDE utilises and enhances generic instrumental configuration of a planetary mission
Science case for generic PRIDE

• Direct characterisation of the orbiter (and surface elements?) signal by means of “VLBI tracking” and radial Doppler measurements

• VLBI estimates of the S/C state vector
  • Tidal deformations, seismology and tectonics of planetary bodies
  • Gravimetry
  • Atmosphere dynamics and climatology (if there is an atmosphere…)
  • Input to the fundamental physics package (GAP)

• Radio occultation observations (e.g. Jovian magneto-/iono-sphere)

• “Cruise” science plus mission diagnostics (“health check”)

• High degree of synergy with in situ measurements

• Complementary to DeltaDOR measurements

plus

• Direct-to-Earth (DtE) delivery of critical data (e.g. via SKA)
**PRIDE: the customers**

- **Mercury**: ESA-JAXA BepiColombo, 2014
- **Venus**: CNES EVE and RSA Venera-D, ~2018?
- **Moon**: ESA NEXT and Chinese Chang’E-2
- **Mars + Phobos**:
  - **RSA Phobos-Grunt**, 2011
  - **ESA ExoMars**, 2016?
- **Jupiter + Europa, Ganymede, Callisto**
  - **ESA-NASA Europa-Jupiter System Mission (EJSM)**, 2020
- **Saturn + Titan, Enceladus**
  - **ESA-NASA-JAXA Titan Saturn System Mission (TSSM)**, 2022?

*All the above brings in new (large!) user community*
Outer Planet missions and SKA

- Phobos-Grunt
- BepiColombo
- ExoMars
- EJSM

TSSM

• Perfect match of timelines
• Potentially rewarding reciprocity

SKA era
ESA Cosmic Vision and NASA Flagship proposals

~4B projects, compete for launch in 2020-2022
### PRIDE-EJSM vs Huygens VLBI tracking

<table>
<thead>
<tr>
<th>Mission</th>
<th>Distance</th>
<th>Transmitter power/gain</th>
<th>Band</th>
<th>Time resolution</th>
<th>Delay noise</th>
<th>Positional accuracy (lateral)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[AU]</td>
<td>[GHz]</td>
<td>[s]</td>
<td>[ps]</td>
<td>[m]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Huygens VLBI</td>
<td>8</td>
<td>3 W / 3 dBi</td>
<td>2.0 (S)</td>
<td>500</td>
<td>15</td>
<td>1000</td>
</tr>
<tr>
<td>PRIDE EJSM</td>
<td>5</td>
<td>10 W / 6 dBi</td>
<td>8.4 (X)</td>
<td>10</td>
<td>3</td>
<td>70</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>32 (Ka)</td>
<td>10</td>
<td>1</td>
<td>23</td>
</tr>
</tbody>
</table>

Conservative estimate, today’s technology
- Minimal special requirements for the on-board instrumentation
- In-beam “Orbiter-Probe” calibration can improve SNR further

GPS accuracy anywhere in Solar System
DtE for EJSM with SKA

BPSK + error control coding

30–50 bps with \( \sim 10^{-4} \) – \( 10^{-3} \) BER achievable

Omnidirectional transmission, 1–3 W

Fridman et al., 2008, SKA Memo No. 104
**Closer to Earth: the DtE case for ExoMars**

ExoMars parameters
- Transmitter power: 12 W
- Unmodulated carrier: 25%
- Antenna gain: 1
- Band: 400 MHz
- Distance: 0.7 – 2.2 AU

SKADS technology at work:
- NCross+BEST
- EMBRACE (4 tiles)
- Tsys = 100 K

*Fridman et al. 2009, in prep*
Expect unexpected spin-offs...

Water maser detection in Enceladus – as a Huygens VLBI tracking spin-off
(spectral line single dish experiment in VLBI continuum mode…)

~350 “in gap” hrs at Medicina and Metsähovi; in collaboration with INAF, HUT, U Kentucky

- Puzzling physics
- Ongoing study

Pogrebenko et al. 2009, IAU Symp 263 (Rio), in press
SKA as a PRIDE and DtE facility

- Sensitivity gain over a large DSN-style antenna >100
- Operational life of pathfinders (e.g. AAVP) coincides with e.g. Phobos-Grunt (2012+) and ExoMars (2016+)
- Operational life coincides with major next Outer Planet missions (2022+)
- Data rate of DtE Huygens-style (~10 W) probe signal on Earth with SKA is possible at 30–100 bps