Lunette: Lunar Farside Gravity Mapping by Nanosat

Kieran A. Carroll, Gedex Inc.
Henry Spencer, SPSSystems
Jafar Arkani-Hamed, University of Toronto
Robert E. Zee, UTIAS Space Flight Laboratory
Moon Rush

- Almost all major space agencies worldwide are now pursuing Lunar missions
- ESA: SMART-1 in Lunar orbit now
- “Moon Race” in Asia: Japan, India, China all developing missions to fly before 2008
- NASA’s Vision for Space Exploration
- Some private Lunar mission teams planning to use Russian equipment and launch services
- CSA space exploration program now open to Lunar mission proposals
NASA’s Lunar Exploration Program

• First stage in President Bush’s Vision for Space Exploration:
  – NASA’s new marching orders
  – Announced January 2004
• Immediate goal is reconnaissance, with Lunar Reconnaissance Orbiter to launch in 2008
• Followed by:
  – Other orbiters
  – Unmanned landers
  – Manned missions after 2015, followed by permanent bases
  – Resource exploration/exploitation: ice first, then minerals?
  – Manned Mars exploration after 2020
• Anticipating a favorable funding response from Congress, NASA has reorganized around this as its new principal objective.
A Role For Small Satellites

- Like all past planetary missions, current Lunar missions are all planned on the “big-sat” paradigm:
  - Maximize cost-effectiveness by manifesting many payloads per mission
  - Effectiveness is high, but so is cost, and schedules are slow
- Microsats and nanosat offer valuable niche-mission opportunities:
  - Cherry-pick medium-value, easy-to-achieve objectives
  - Keep to one or two instruments per satellite, avoid complex mission operations
  - Allows small-team approach, very low cost per mission
  - Precedents: Very successful LEO microsat science missions such as MOST, CHIPSat
Proposed Niche for Nano/Microsats:  
A Lunar Gravity Mapping Program

- Important science
- Valuable contribution to exploration
- Achievable via low-cost, stand-alone small satellites (if done right!)
- *This class of mission is affordable within the Canadian space exploration budget*
- Strong synergy with terrestrial exploration applications
- Provides a natural entrée to subsequent involvement in resource extraction and exploitation activities
Lunar Gravity Mapping for Science

- Fundamental questions regarding the Moon’s formation
- “Nearside/farside dichotomy” (crust thin on nearside, thick on farside)
- Nature of mass concentrations (mascons) below the maria and some craters
- Enables improvement in topography modeling from laser altimeter data
- Key to understanding Lunar geological formations:
  - These in turn are key to prospecting for high-grade mineral deposits, by understanding if mare basalts originate near the surface or from the mantle
- NASA HQ Code S sees Lunar gravity mapping as a priority
- Nearside maps complete to 10-20 mGal level, via radio tracking of Apollo, Clementine, Lunar Prospector
- Farside maps all inferred from nearside tracking data, likely very inaccurate
- Lunette P.I. was part of team that attempted to fly a pair of subsatellites to rectify this (1970, Apollo 18), other attempts since then failed to achieve funding due to high cost (e.g., ESA’s $400M MORO proposal)
Current Lunar Gravity Models
(Lunar Prospector)

- Accurate topographical mapping requires an accurate gravity model
- Geological models are derived from both topography and gravity models
Lunar Gravity Mapping for Exploration

- **Near-term:**
  - Map farside mascons to allow precise unmanned landings
  - Improve Lunar geodetic model to enable precise topographical mapping from orbit

- **Medium-Term:**
  - Provide geological context to support base site selection
  - Help identify areas with potential high-concentration ice/mineral deposits
  - Terrestrial analogy: “sovereignty mapping” (government surveys) with results disseminated

- **Long-term:**
  - Detailed site surveys to identify drilling/excavation targets: drilling/digging holes is very expensive!
  - Terrestrial analogy: airborne geophysical surveys of claims

- **The Gravity Gradiometry Advantage:** Signals not shielded by intervening material
1. **Lunette**
   - Near-term nanosat-class mission
   - Complete farside gravity model to current nearside level (10-20 mGal)

2. **AGGLO: A Gravity Gradiometer in Lunar Orbit**
   - Medium-term microsat-class mission
   - Improve global Lunar gravity model to 1-2 mGal equivalent

3. **Lunar Surface Gravity Gradiometry**
   - Long-term lander mission
   - Deploy mobile gravity gradiometer(s)
Lunette

- Science mission: *to map Lunar farside gravity field, to 10-20 mGal*
- Free-flying nanosatellite, *ejected from and flying in formation with* a parent satellite, both in low Lunar orbit, measuring *relative range rate* using radio tracking
- Complements JAXA’s SELENE “high/low” mission
- ~5 kg, ~$2-5M (if done as SFL nanosat)
- Science instrument: ranging radio transponder
- Bus needs 3-axis attitude control and propulsion
- Initially proposed as a subsatellite payload for ISRO’s Chandrayaan-1 lunar satellite:
  - Was short-listed; complements ISRO LIDAR payload
  - Didn’t make final cut (CSA funding decision process slower than ISRO’s payload selection schedule)
- Suitable for flight with any of several upcoming Lunar polar orbiting missions
Inter-Satellite Relative Speed Signals

- Example scenario:
  - Mascon:
    - 20 km deep
    - 35 km diameter
    - 1.5E16 kg excess mass
  - Fly-over of mascon:
    - From -300 km to +300 km horizontally
    - 50 km altitude
    - 1.655 km/sec velocity
- Peak gravity anomaly:
  - 20 mGal (2e-4 m/sec^2)
- Peak inter-satellite speed variation:
  - Horizontal: 4 mm/sec
  - Vertical: 7 mm/sec
- Lunette target speed measurement sensitivity: 1 mm/sec after 10 seconds of averaging
Baseline Design: Based on SFL’s CanX-3/BRITE Nanosat Bus

- Bright Star Photometry nanosat (“Nano-MOST”)
- 15x15x15 cm, <4 kg
- Two fixed S-Band monopole uplink antennas
- Two S-Band patch downlink antennas
- Two fixed UHF monopole beacon antennas
- Two GPS patch antennas
- Body-mounted solar panels, each containing one or two strings of two 26% efficiency TJ cells:
  - 5+ W maximum power
  - 4.1 W nominal power
  - 1.5 W survival power
Lunette Technology

- **Basic Nanosat Bus and Ejection System:**
  - U of T/Space Flight Laboratory CanX nanosat program
  - One satellite built and flown, funding secured for next 2 missions
- **Reaction Wheel:**
  - Prototype built, will be test-flown on CanX-2
- **Star Tracker:**
  - Baseline: software from MOST star tracker, CMOS camera initial design/imager testing under BRITE mission studies
- **Nanosat propulsion (25-75 m/sec):**
  - Baseline vendors identified, flight hardware built for 25m/sec, breadboard testing done for 75m/sec
  - Alternative is SFL-developed nanosat propulsion
- **Low-power transponder:**
  - Baseline: based on MOST S-band transmitter
- **Processing of tracking data to extract gravity models:**
  - Baseline: use NASA GSFC/JPL code via US team members
  - Alternative is to develop new software for that
AGGLO: A Gravity Gradiometer in Lunar Orbit

- Gravity Gradient:
  - The rate of change (in x, y, z directions) of local gravity vector
  - 6x6 tensor, satisfying Laplace’s equation
- Previous gradiometers use “In-Line Responder” design (paired accelerometers): very sensitive to platform motion
- Gedex developing a compact, robust Orthogonal Quadropole Responder (OQR) gradiometer for airborne geophysics exploration
- Technology development underway will make this suitable for use in space on planetary-microsat-class platform
- ROM mission cost: $20-30M
- Co-manifesting a LIDAR desirable, for terrain corrections and topography mapping
- Will need orbit maintenance and attitude control propulsion, and a ride to Lunar polar orbit
Gravity and Gravity Gradient Signals

- Example scenario:
  - Mascon:
    - 20 km deep
    - 11 km diameter
    - 1.5E15 kg excess mass (1/10 the mass of previous example)
  - Fly-over of mascon:
    - From -300 km to +300 km horizontally
    - 50 km altitude
    - 1.655 km/sec velocity
  - Peak gravity anomaly:
    - 2 mGal (2e-5 m/sec^2)
  - Peak gravity gradient anomaly:
    - ~0.6 Eo (5.8e-10 m/sec^2/m)
  - Gedex target airborne gravity gradient anomaly sensitivity: <0.3 Eo after 10 seconds of averaging
**Lunar Gravity Mapping Team**

- **Jafar Arkani-Hamed:**
  - Lunette science team PI, University of Toronto Physics Dept
  - Geophysicist/planteologist, Lunar morphology researcher, mascon specialist

- **Gedex:**
  - Geophysics exploration systems engineering company
  - Developing a new-technology airborne gravity gradiometer for terrestrial mineral, oil and gas exploration

- **UTIAS Space Flight Lab:**
  - Bus contractor for MOST and NEOSSat
  - Canadian pioneer in nanosat development: CanX-1 launched, CanX-2 nearly complete, CanX-3/4/5 in development

- **Henry Spencer, SPSSystems:**
  - Software architect for MOST, NEOSSat microsats
  - Mission architect for CRAFTI and PARTI small-body microsat-class missions