



*Space Missions*



# Building on Canadian Capabilities for Space Resource Missions

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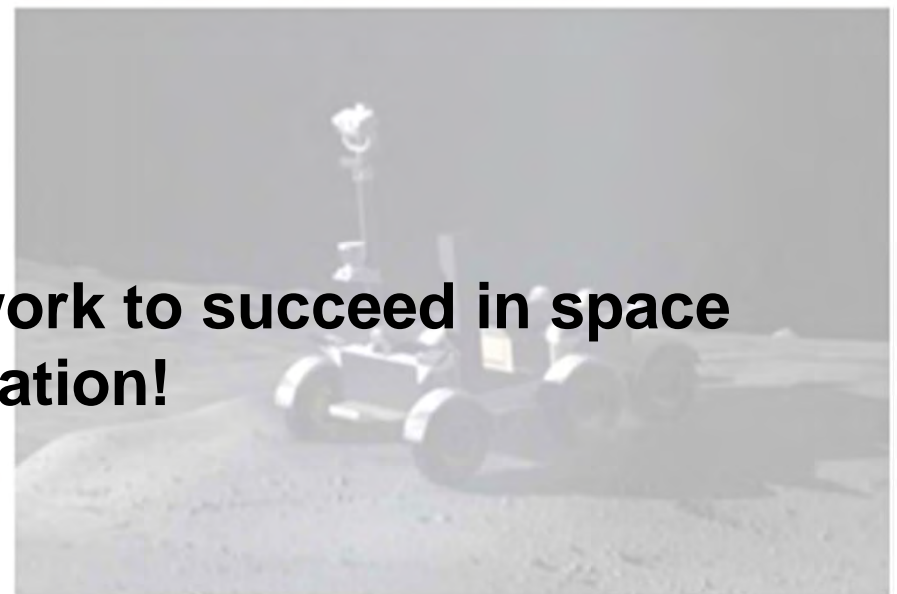


## Building on Canadian Capabilities for Space Resource Missions:

- Space resource science and technology mission building blocks
- Canadian historical perspective
- Status and future pursuits



**It takes Canadian Teamwork to succeed in space exploration!**



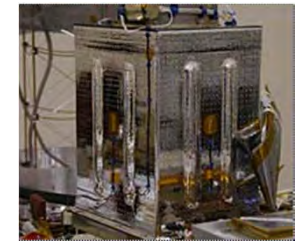




- Space resource science and technology building blocks:

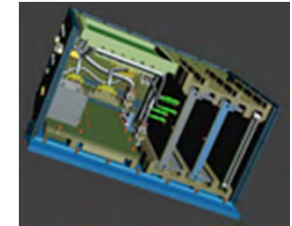
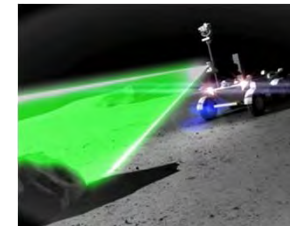
- **Orbiting / Delivery Elements**

- Spacecraft
- Sensors



- **Landed elements**

- Roving / Mobility, Autonomy
- Sample acquisition and handling
- Sensors, GN&C



- **Science**

- **Operations**

- **Partnerships:**

- Government – Industry
- Between Industry
- With Academia and Scientists





# Heritage ..... 1970s-2000s



## Human Spaceflight



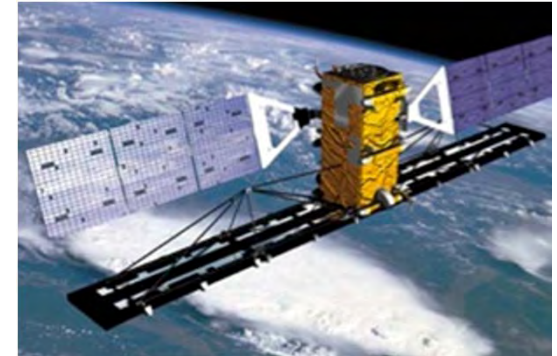
**Shuttle & ISS Canadarms (1986+)**  
*Shuttle deployment & servicing, ISS assembly*

## Orbital Robotics



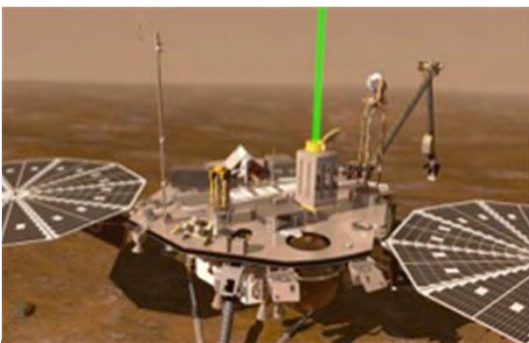
**Autonomy. Orbital Robotics (2001+)**  
*Unmanned rdv & servicing*

## National Space Missions



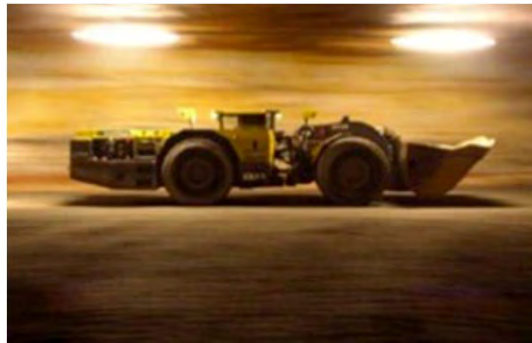
**Remote Sensing, SatCom Satellites**  
*Radarsat, Radarsat-2, Cassiope*

## Planetary Exploration



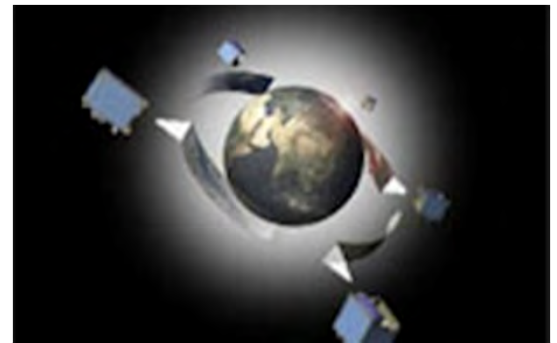
**Mars Exploration (2008+)**  
*Science instruments & robotics*

## Space-Terrestrial Coop



**Terrestrial Robotics – e.g. Mining**  
*Mine Automation & Vehicle Autonomy*

## Commercial Space Missions



**Commercially-funded space**  
*Rapideye small sat constellation, Sat Comm*



- Not yet, But....
- Before we can use a rover, we need a spacecraft to deliver it.
- And, a rover is itself a specialized spacecraft, with all the systems and ops aspects of a S/C such as a satellite:
  - Power generation, management and storage
  - Propulsion / attitude control / steering
  - On-board computation
  - Sensors and navigation
  - Science (eg. Earth observation satellite)
- Canada has been the Prime Contractor on successful satellite programs dating back to the 1980's:
  - Radarsat 2 (MDA)
  - Cassiope, RapidEye (MDA)
  - Radarsat (Spar Aerospace)
  - Anik ComSats (Spar Aerospace / Telesat)
  - SciSat (Bristol Aerospace)
  - MOST, MicroSats (UTIAS / SFL, etc)

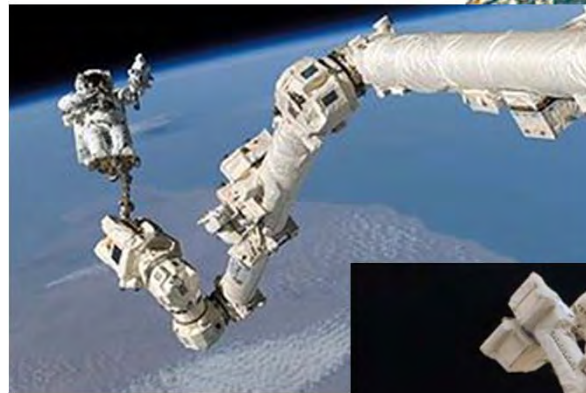
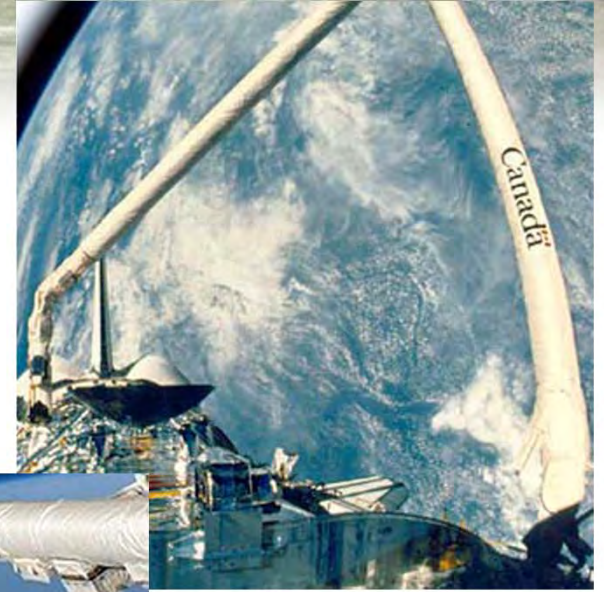




- On-Orbit Segment / Delivery of Rover
  - RadarSat, Radarsat2
  - Orbital Express, XSS11
  - ✓ Flight Experience
  - ✓ More in Development
- Instruments and Payloads:
  - Phoenix, APXS
  - OSIRIS-Rex OLA
  - ESM Rover Payloads / Tools / Instruments
  - ✓ Flight Experience
  - ✓ More in Development
- Rovers
  - CBR
  - MESR, LELR
  - ESM Rovers
  - ✓ In Development



- 1970's-80's: Space Shuttle: Canadarm
- 1990's-00's: Space Station:
  - SSRMS and MBS
  - SPDM (Dexter)
- Space qualified:
  - Software
  - Avionics and motors
  - Mechanisms
  - Interfaces
  - On-Orbit Maintenance
- Programs enabled by CSA.
- Technology developed is still in use today.
- 30+ Years of Ops Experience
- Development of new Canadian industry and suppliers.
- International Partnerships





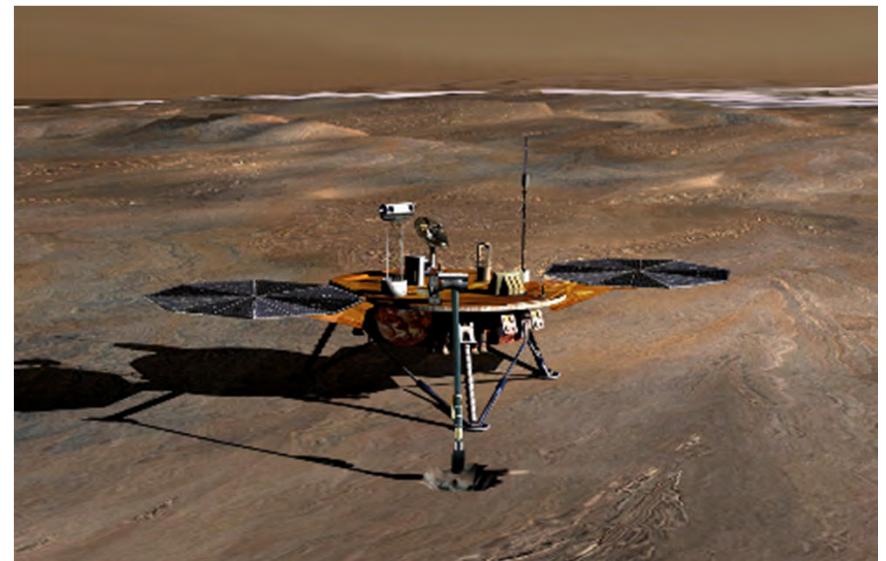
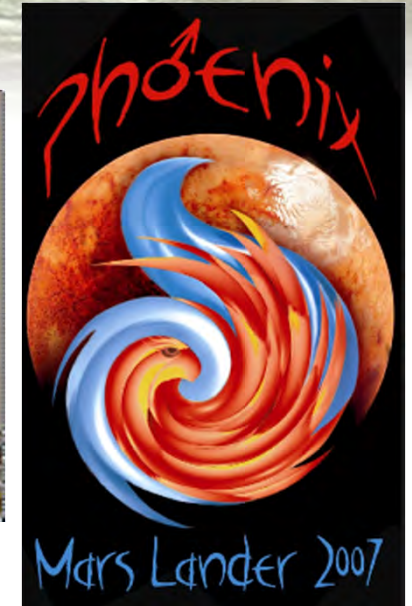
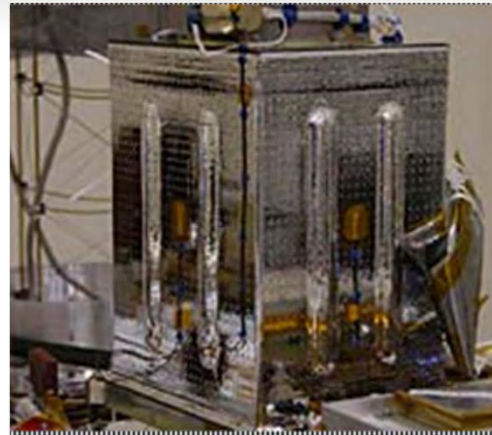
- Boeing / MDA, built for DARPA
- Key Servicing Functions demonstrated in LEO for remote servicing missions
- Autonomous vehicle capture
- Autonomous Computer and Battery exchange
- Autonomous fluid transfer
- Visual Servoing
- Control is remote from operator and robot reacts to and accommodates real time sensed environment







- Phoenix 2007 Mars Lander
- MET – Meteorological Station
  - Pressure/Temperature
  - Scanning Lidar
- Developed by CSA
- Prime Contractor was MDA
- Science Team:
  - York U, Dalhousie
  - U of Arizona
- Industrial Partners
  - Optech
  - Passat (Laser)
- Successful Mission, now Complete.

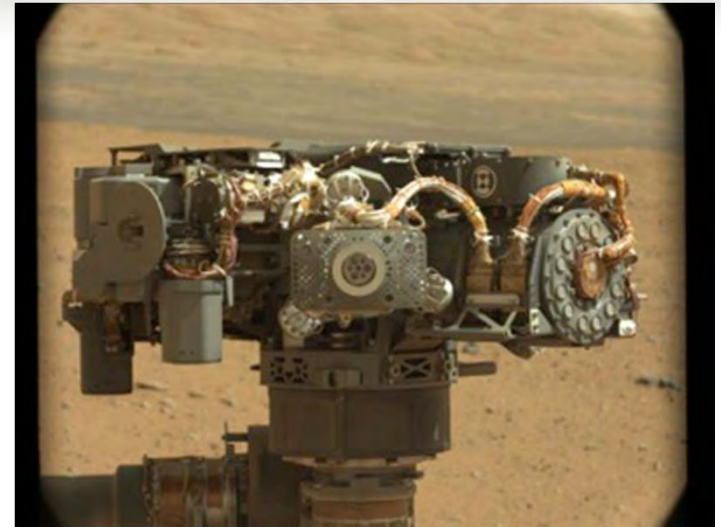




## Canada on Mars: Mars Science Lab - APXS



- “Curiosity” Rover - NASA JPL Mission
- Canada’s Contribution:
  - Alpha Particle X-Ray Spectrometer
- X-Ray ‘camera’ that tells scientists the elements in rocks and soils
  - Radioactive material “queries” the target and an X-ray detector reads to answer
- Successfully operating on Mars
- Key measurements already:
  - Guiding site selection and drilling ops
- Built by MDA for CSA
- Science Team
  - PI, Ralf Gellert, U of Guelph
- Industrial Partners
  - Ketek, DRS







## Canada's Growing Resume: Asteroid Recon



- OSIRIS-Rex: Asteroid Sample Return Mission
- NASA-led \$800M 3<sup>rd</sup> New Frontiers Mission
- Launch: September 2016
- CSA contribution: *OSIRIS-Rex Laser Altimeter (OLA)*
- Instrument maps asteroid from 7k to 250m
- Primary functions: science & recon
  - Generate a 3D model
  - Topography (slope, craters, reflectance)
    - characterization & sample site selection
- Secondary support to rendezvous / nav
- 3<sup>rd</sup> Canadian planetary flight instrument
- Science Team
  - U of Calgary, York U
- Industrial Team
  - MDA, Optech, Left Hand Design, DRS





# Canadian Rover Development, 2005 - Present



Tech Development



Mission-Focused Analogs



Field Deployments / Ops



ESM

Credit: MPB

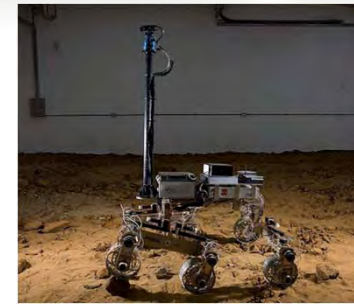


ESM

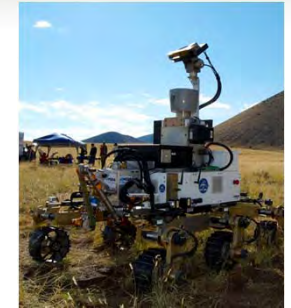
Credit: ESI



Credit: MDA



Credit: MDA / ESA



Credit: MDA



Credit: Penguin ASI



Credit: Optech / NASA



Credit: UTIAS



ESM

Credit: MDA



ESM

Credit: Neptec



Credit: MDA / NASA



Credit: Neptec



Credit: MDA



ESM

Credit: MDA



ESM

Credit: MDA





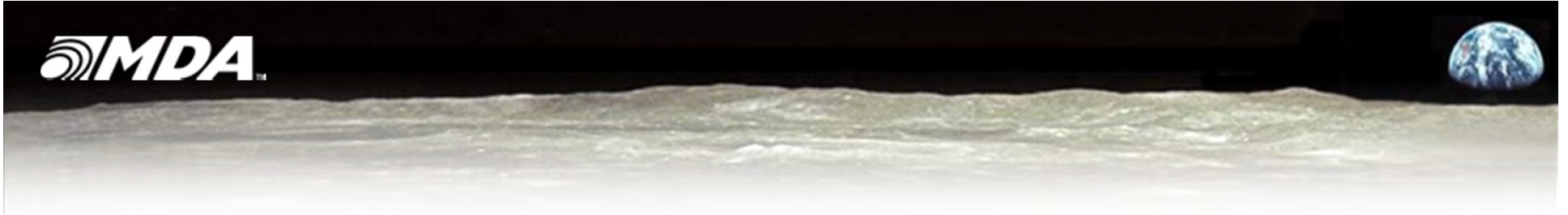
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|--|---|
| <ul style="list-style-type: none"><li>– Phase 0<ul style="list-style-type: none"><li>• Science, Commercial and Space sectors</li></ul></li></ul>                             | RESOLVE<br>CSA STDP Studies                                 |
| <ul style="list-style-type: none"><li>– Phase A<ul style="list-style-type: none"><li>• Concept of Operations</li><li>• Prototyping and Field Deployments</li></ul></li></ul> | MESR, LELR<br>ESM Rovers and P/Ls<br>Instruments            |
| <ul style="list-style-type: none"><li>– Phase B<ul style="list-style-type: none"><li>• Preliminary Design and Prototypes</li></ul></li></ul>                                 | OSIRIS- Rex<br>ExoMars                                      |
| <ul style="list-style-type: none"><li>– Phase C<ul style="list-style-type: none"><li>• Detailed Design and Engineering Models</li></ul></li></ul>                            |   |
| <ul style="list-style-type: none"><li>– Phase D<ul style="list-style-type: none"><li>• MAI&amp;T</li></ul></li></ul>   |   |
| <ul style="list-style-type: none"><li>– Phase E<ul style="list-style-type: none"><li>• Operations and Science</li></ul></li></ul>  | Space Station MSS<br>APXS, OE, XSS-11<br>Canadarm & Phoenix |



- Canada is working towards the next step in our exploration heritage – building towards missions such as RESOLVE and asteroid missions.
- For success, we need to leverage the Canadian capabilities developed.
- Collaboration:
  - CSA
  - Experienced Mission Prime
  - Specialized companies with flight capability / heritage
  - New players /new technologies, flying for the first time
  - Academia / Scientists
- **It takes Canadian Teamwork to succeed in space exploration**







**Thank You.**