

Place Revisiting for Planetary Rovers: An Enabling Technology and Field Testing of Three Mission Concepts

Timothy D. Barfoot, Braden E. Stenning, Jonathan D. Gammell, Chi Hay Tong,
Colin McManus, Laszlo-Peter Berczi, Gordon R. Osinski, Michael Daly, Cameron Dickinson

ICRA 2013 Planetary Rovers Workshop

May 10, 2013



Today's Outline

- enabling technology: place revisiting for planetary rovers
 - *stereo visual teach and repeat*
 - *networks of reusable paths*
- field testing of three mission concepts
 - *robot-only geological investigation in the Sudbury impact structure*
 - *human-robot geological exploration in the Mistastin impact structure*
 - *methane-hunting scenario at the CSA's Mars Emulation Terrain*



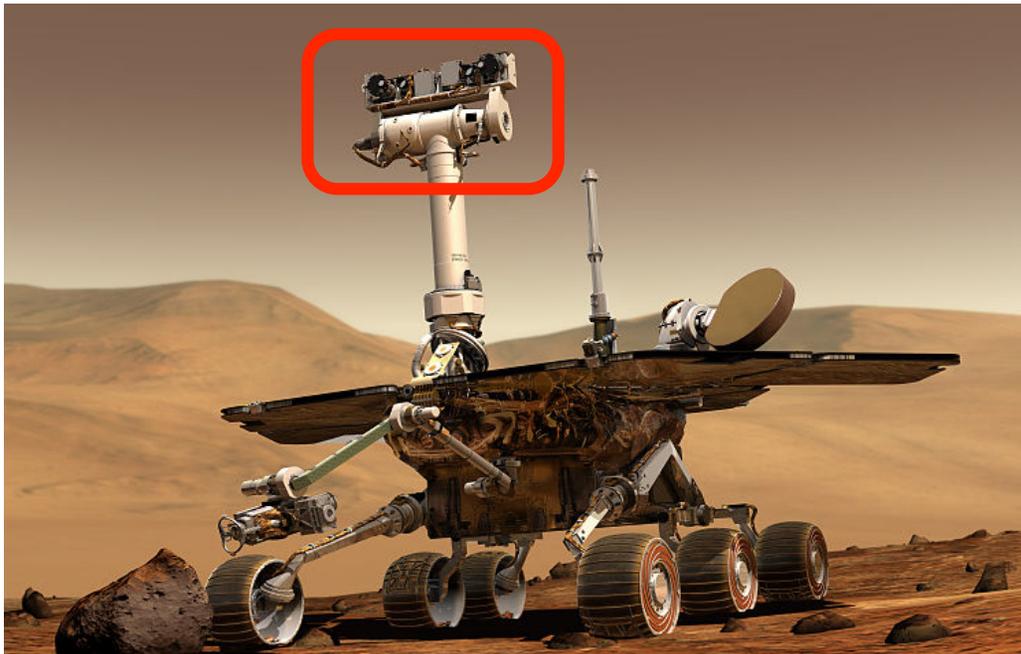
Today's Outline

- enabling technology: place revisiting for planetary rovers
 - *stereo visual teach and repeat*
 - *networks of reusable paths*
- field testing of three mission concepts
 - *robot-only geological investigation in the Sudbury impact structure*
 - *human-robot geological exploration in the Mistastin impact structure*
 - *methane-hunting scenario at the CSA's Mars Emulation Terrain*



Stereo Visual Odometry

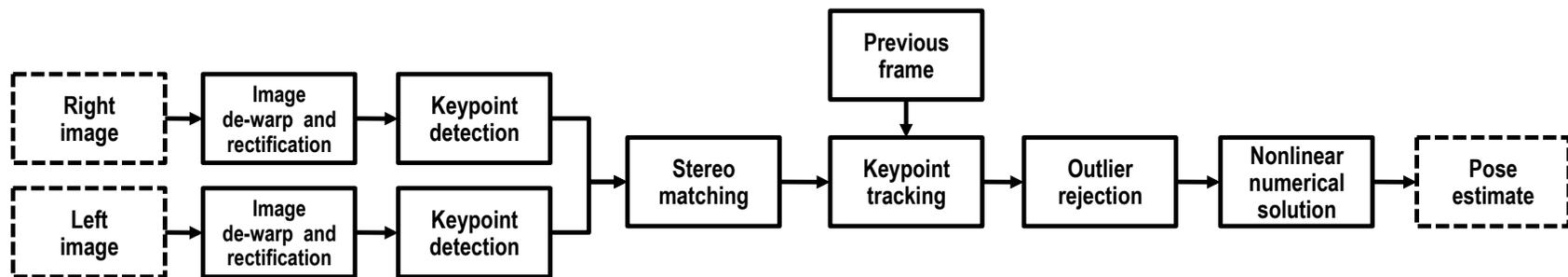
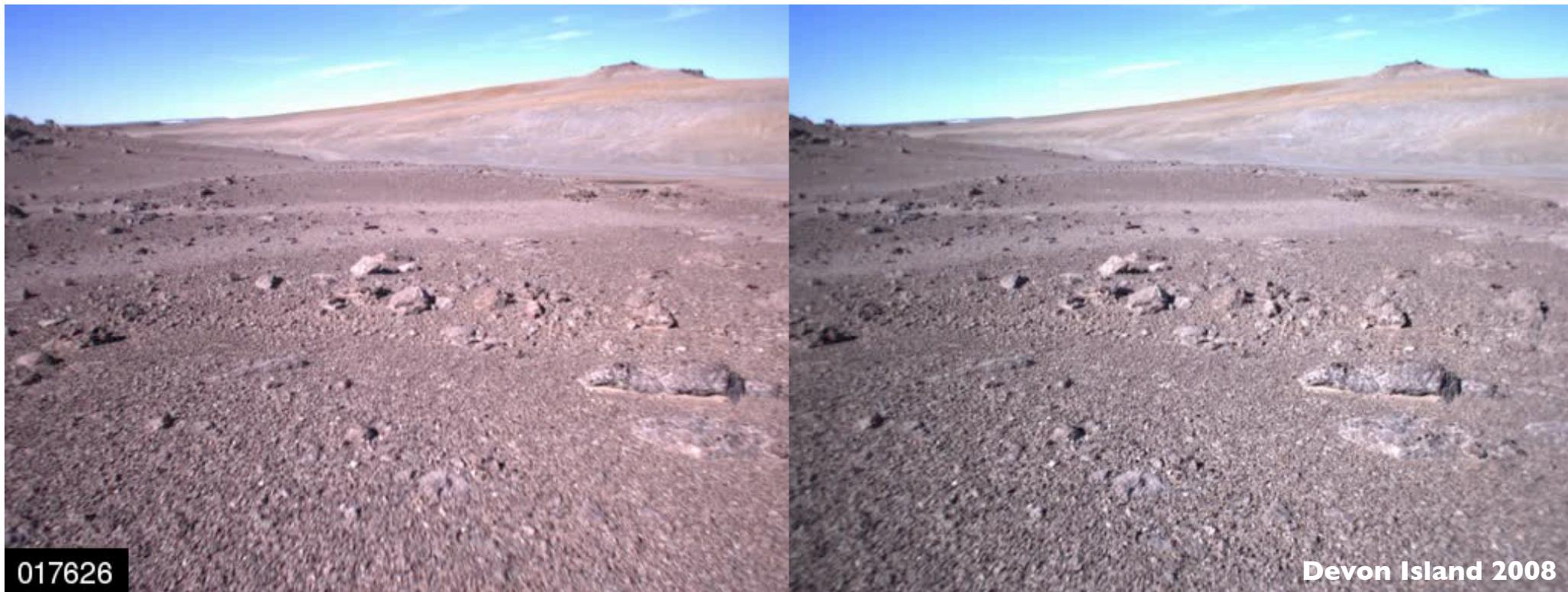
- on nominal terrain, the Mars rovers (Spirit, Opportunity, and Curiosity) use wheel odometry to track position changes
- visual odometry (VO) provides accurate localization in high-wheel-slip environments
- pioneered by Moravec (1980), Matthies (1987) and extended by many others



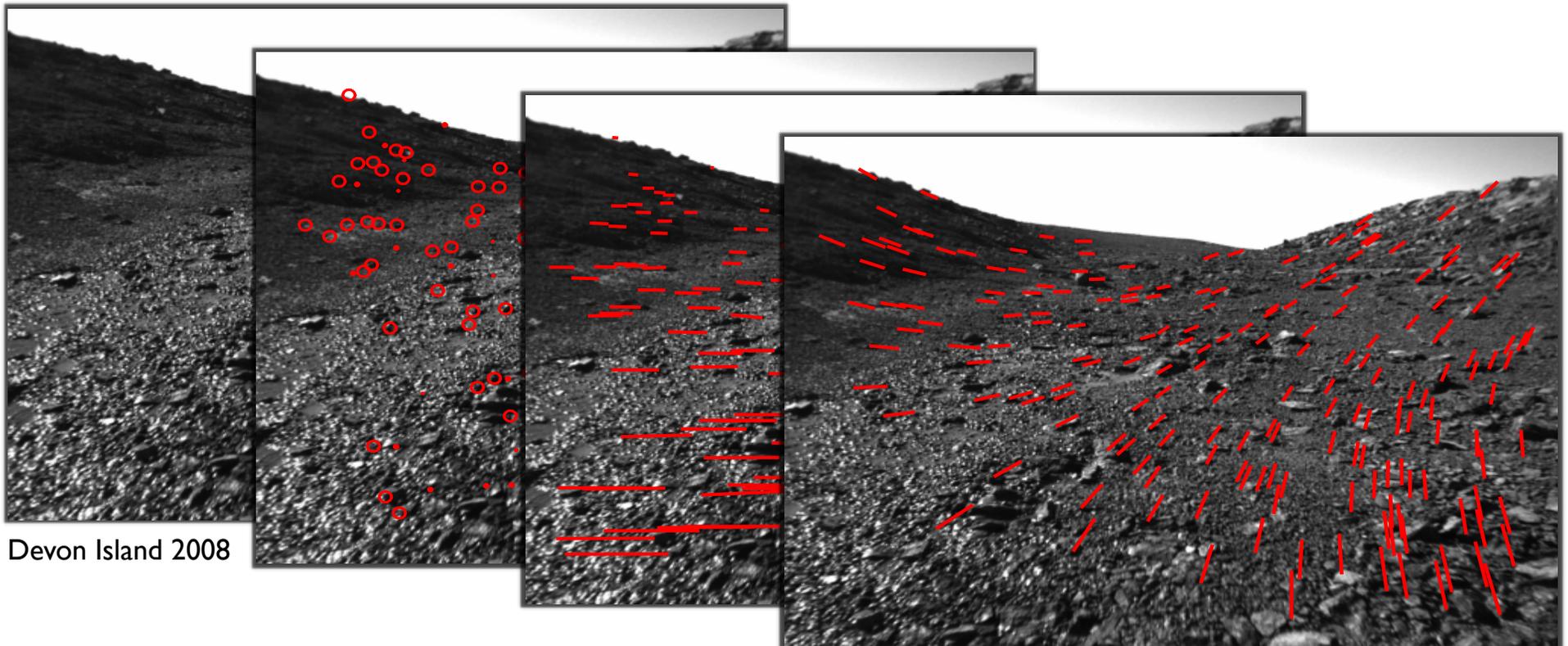
Images: NASA/JPL/Caltech



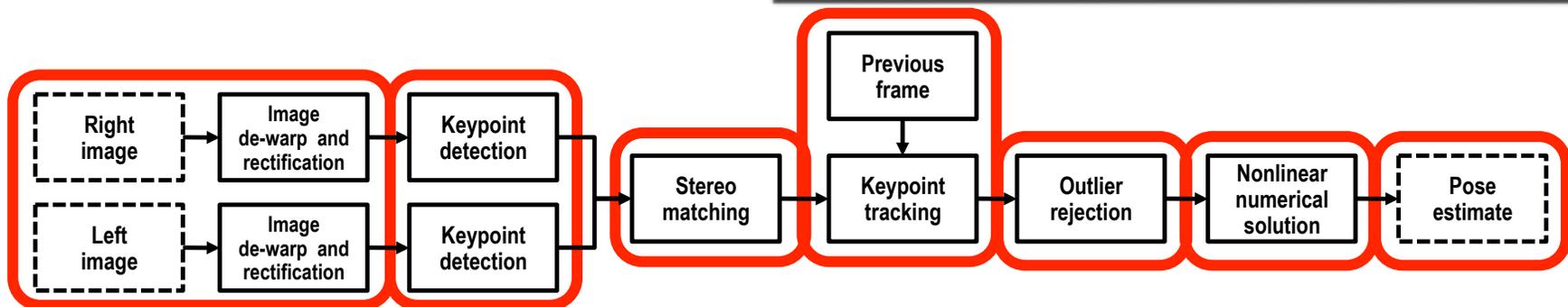
Stereo Visual Odometry Pipeline



Stereo Visual Odometry Pipeline



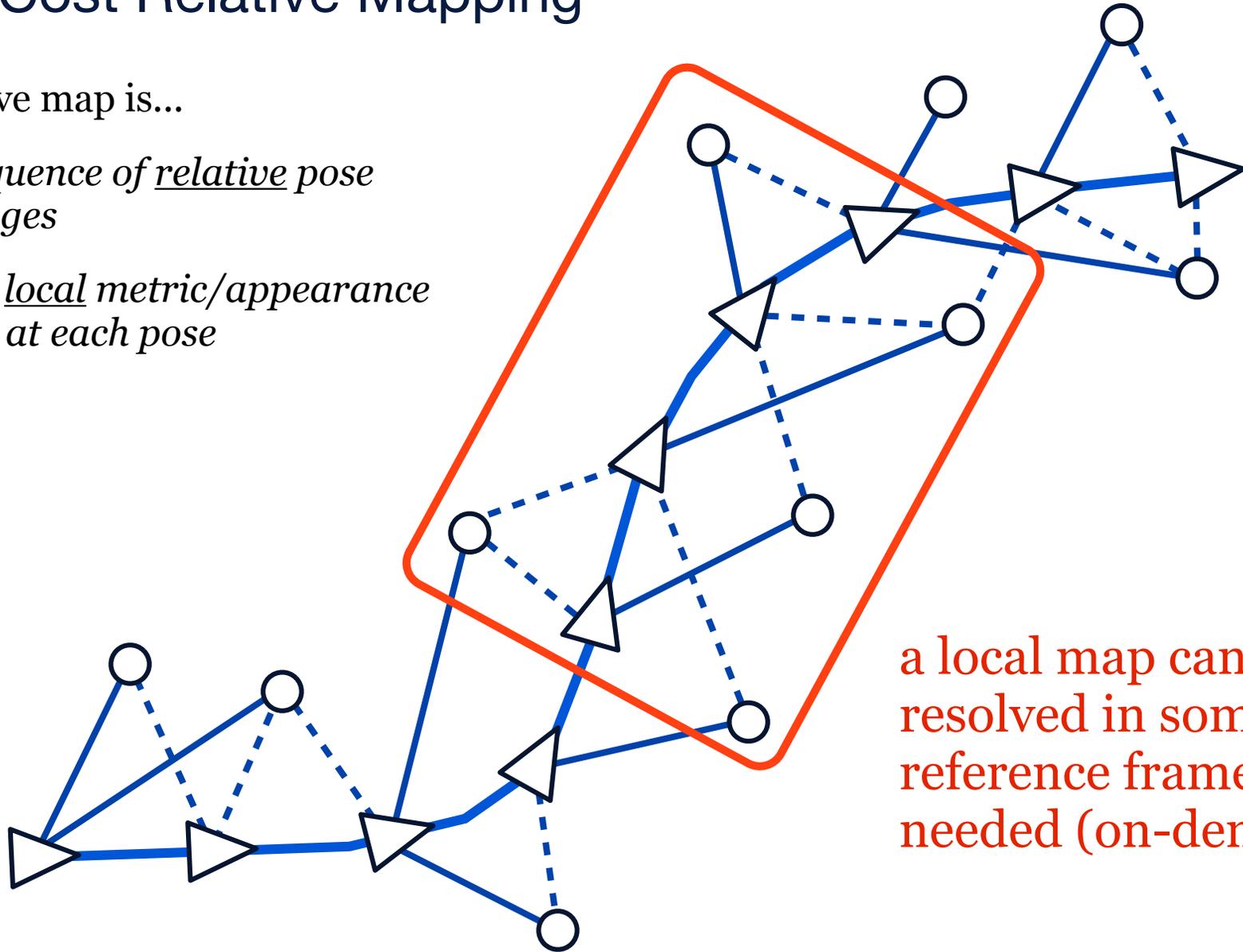
Devon Island 2008



Low-Cost Relative Mapping

A relative map is...

- a sequence of *relative pose changes*
- with *local metric/appearance data at each pose*

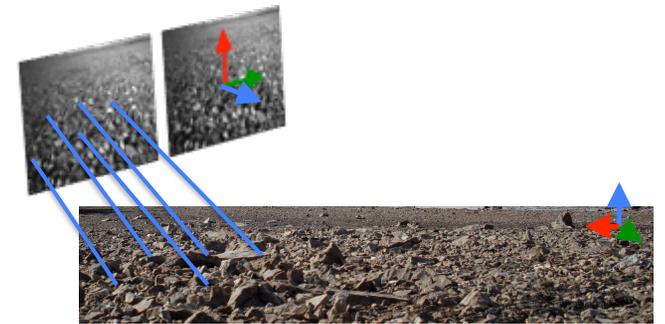
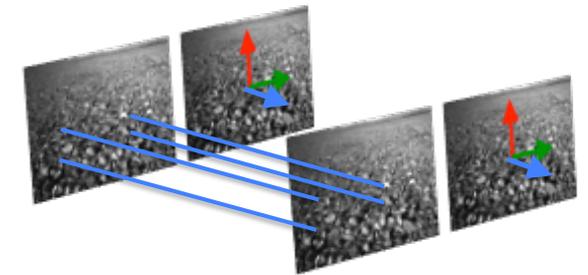
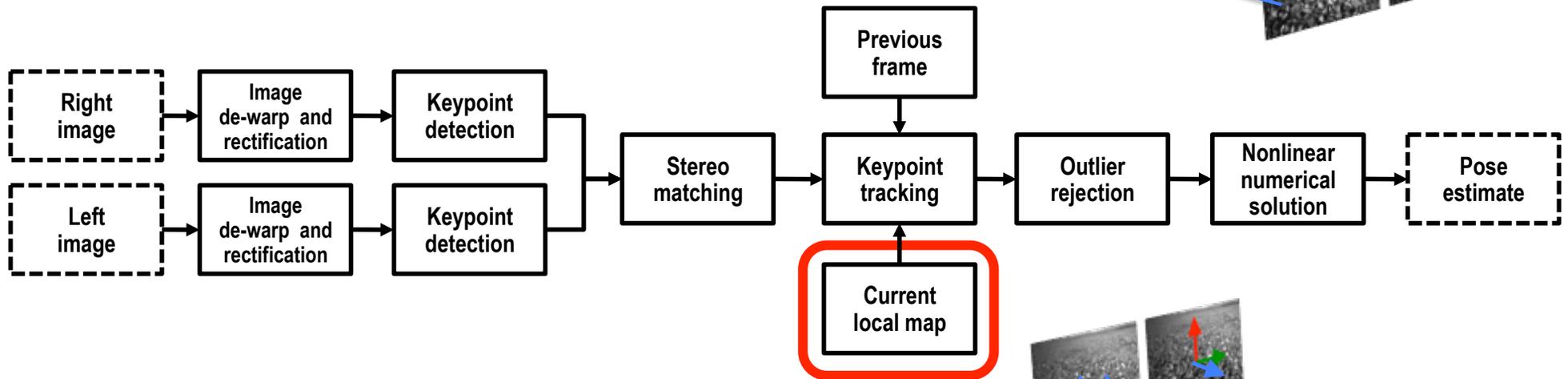


a local map can be resolved in some reference frame as needed (on-demand)



Stereo VT&R: Repeat Pipeline

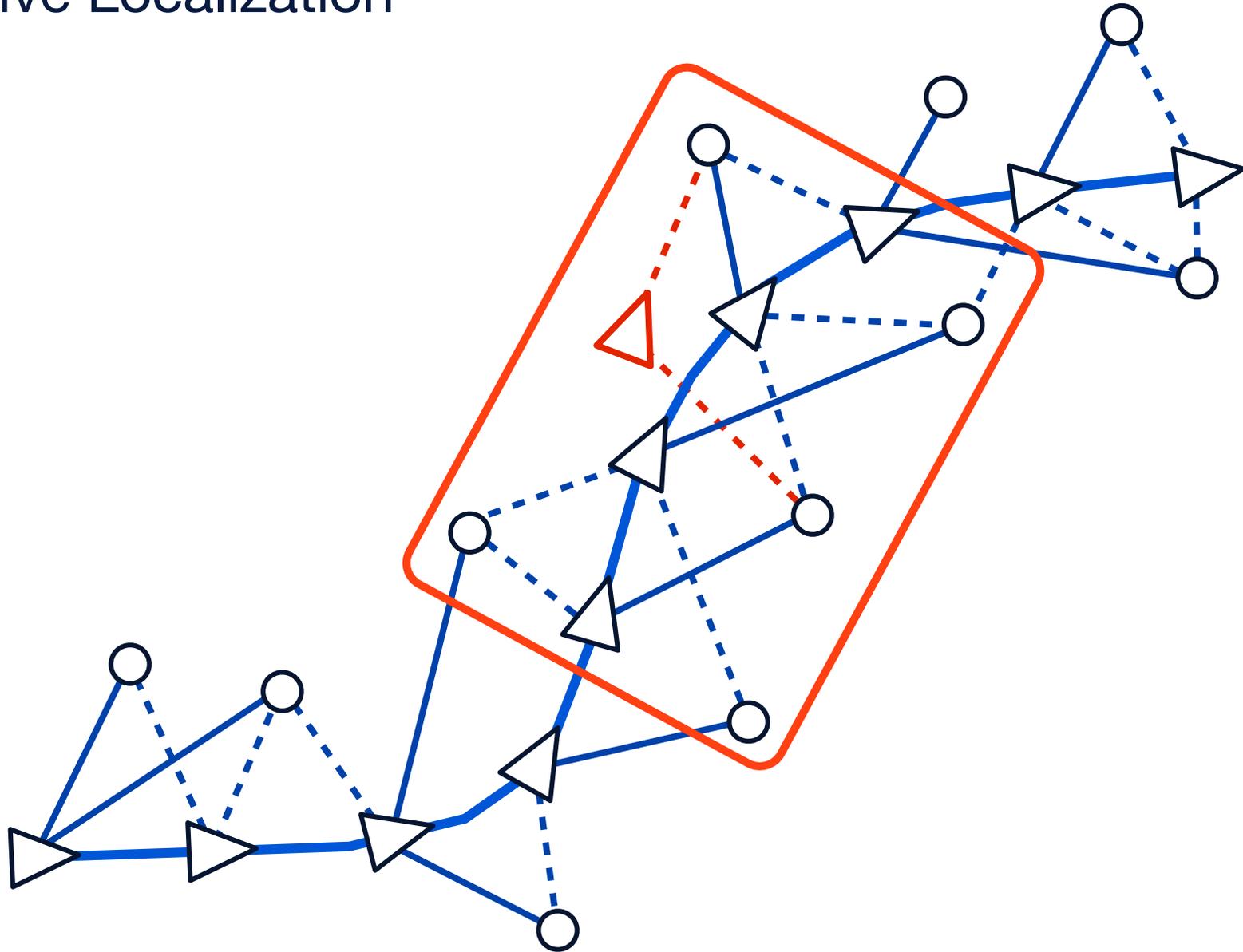
- matching against the previous frame is still performed to carry the system past areas where map matching fails
 - *helps with lighting variations*



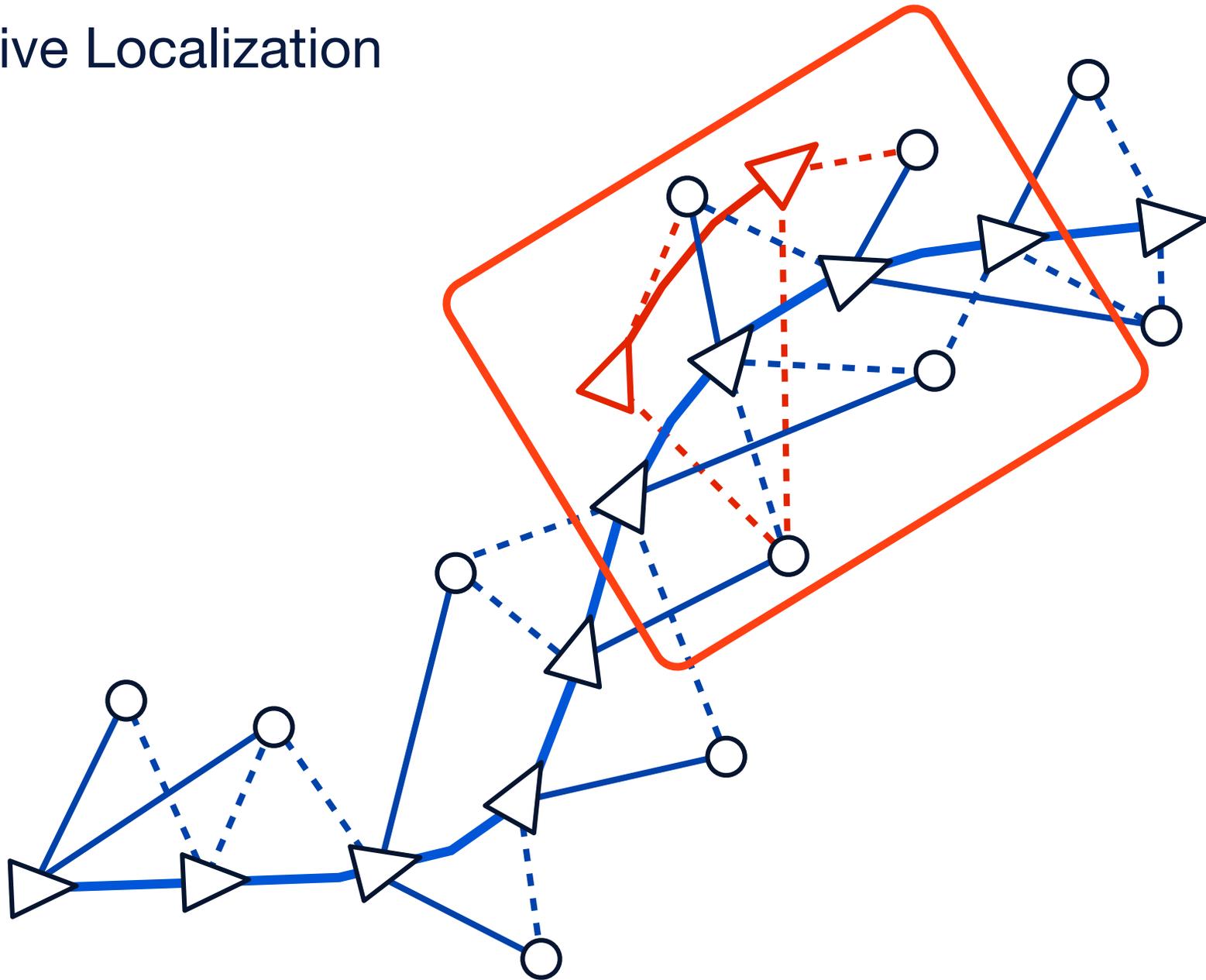
- we also match against the current local map gathered during teaching phase
 - *maps are loaded from disk as needed*



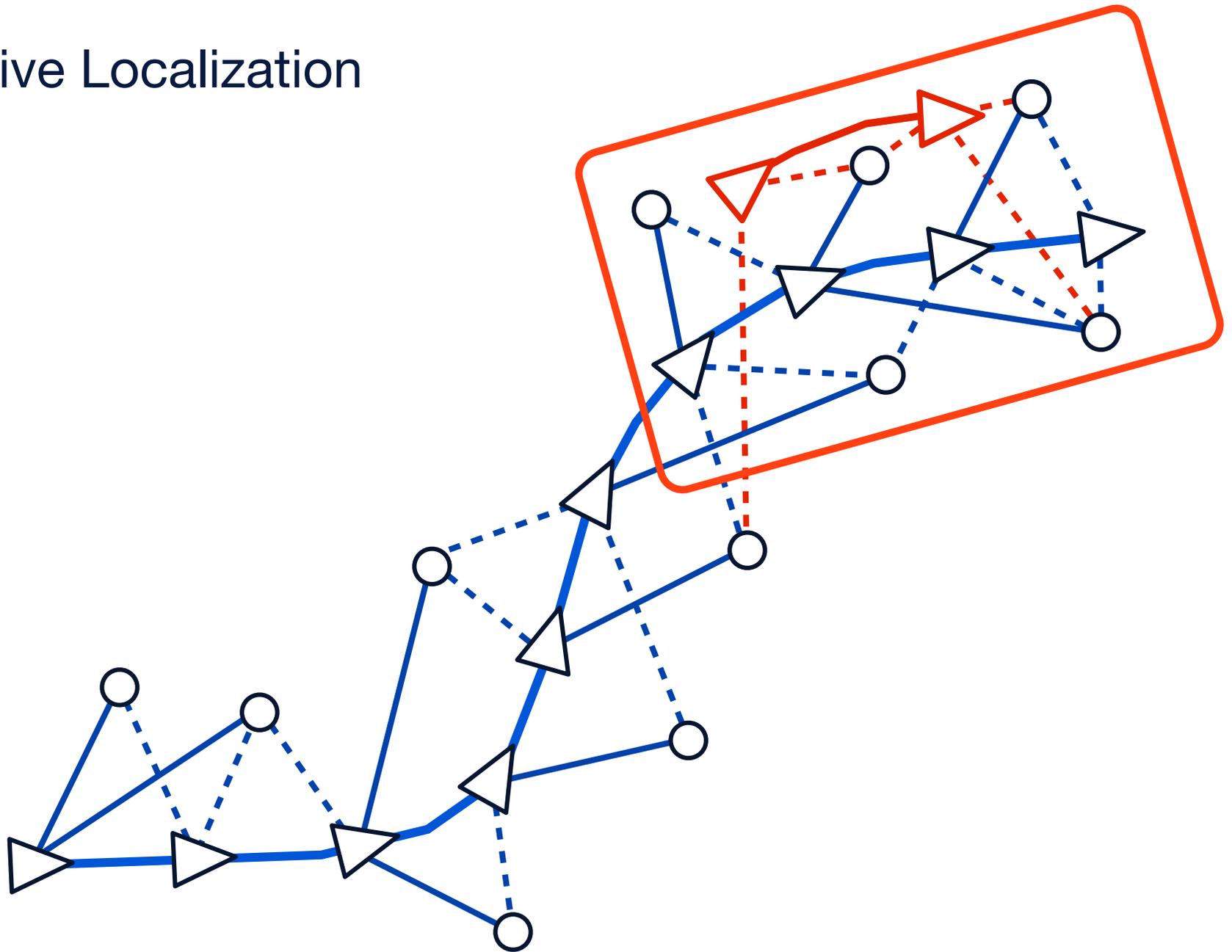
Relative Localization



Relative Localization



Relative Localization



Stereo VT&R Example



Montreal 2012



Institute for Aerospace Studies
UNIVERSITY OF TORONTO



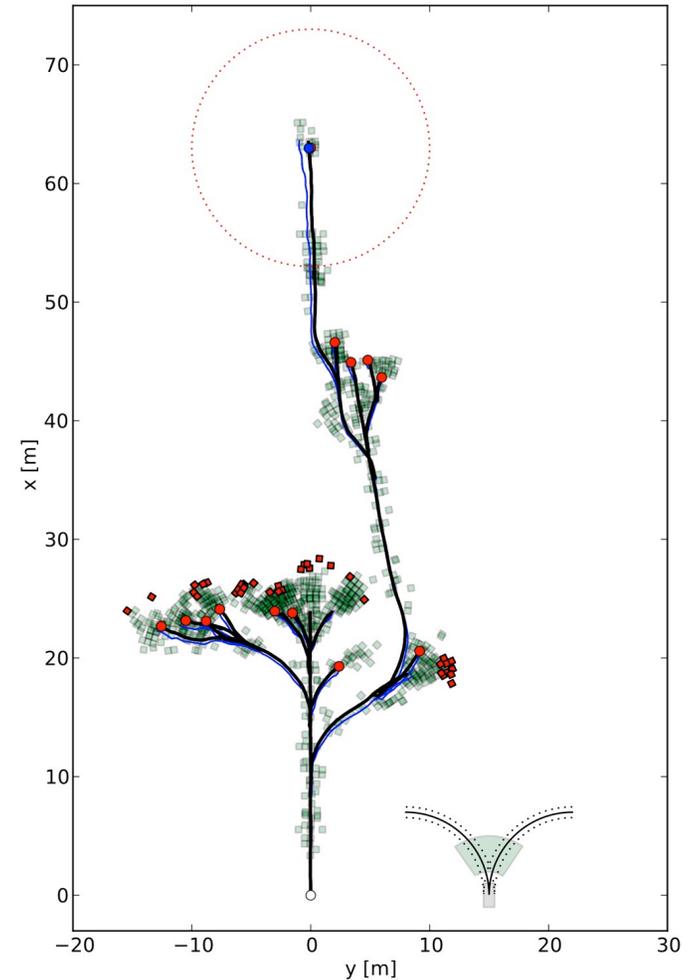
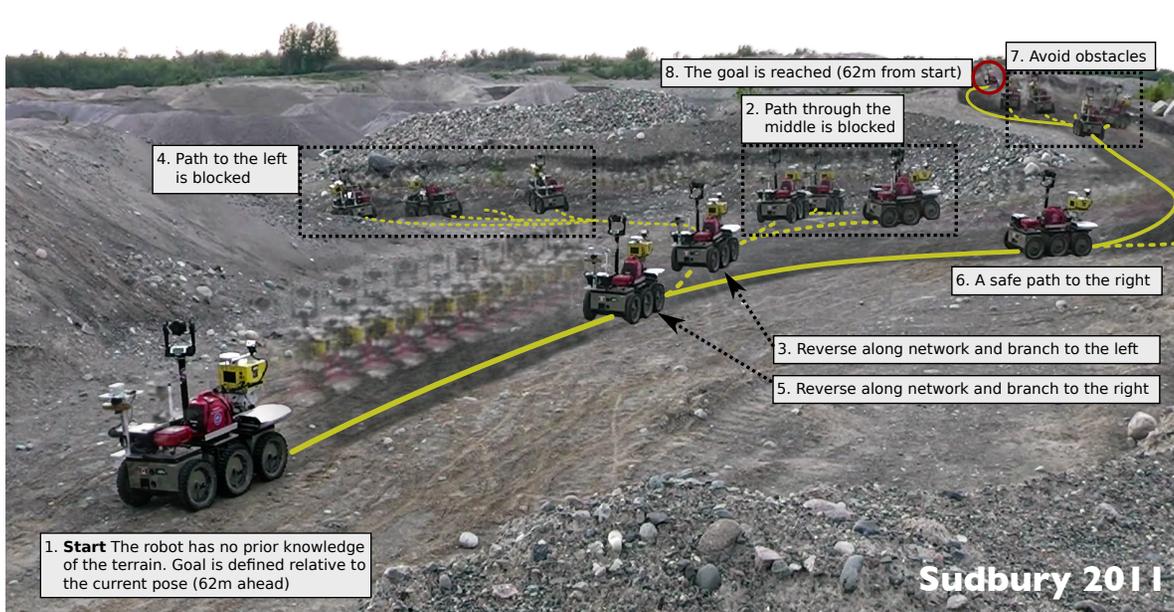
Stereo VT&R Example



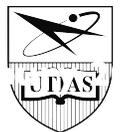
Networks of Reusable Paths: Goal Seeking



Network of Reusable Paths

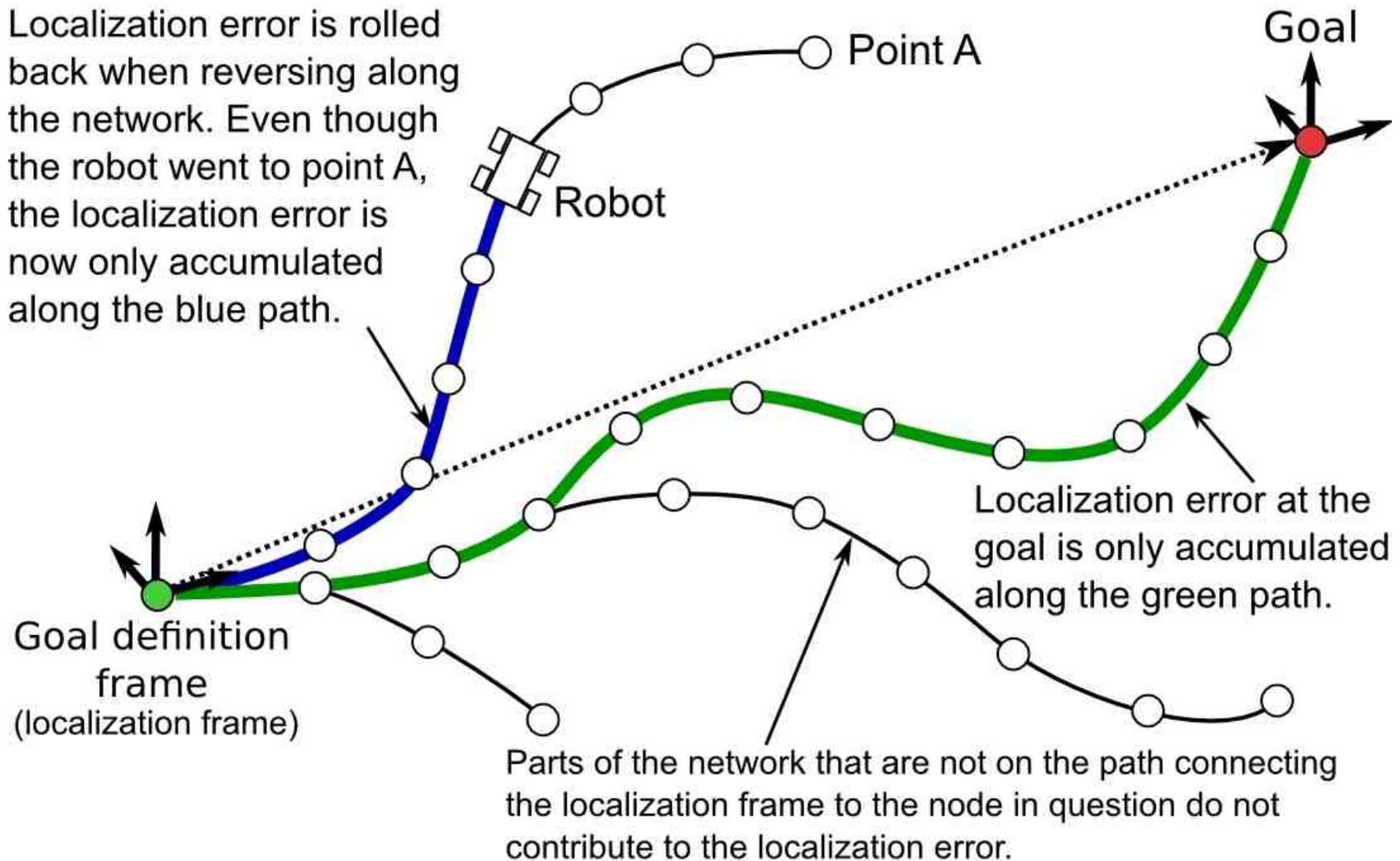


- branch to get around obstacles
- use previously driven paths to backtrack out of dead-ends
- physical embodiment of an rapidly expanding random tree planner
 - *the world is its own map*



NRP Has Some Benefits of SLAM without Loop Closure!

Localization error is rolled back when reversing along the network. Even though the robot went to point A, the localization error is now only accumulated along the blue path.



Today's Outline

- enabling technology: place revisiting for planetary rovers
 - *stereo visual teach and repeat*
 - *networks of reusable paths*
- field testing of three mission concepts
 - *robot-only geological investigation in the Sudbury impact structure*
 - *human-robot geological exploration in the Mistastin impact structure*
 - *methane-hunting scenario at the CSA's Mars Emulation Terrain*



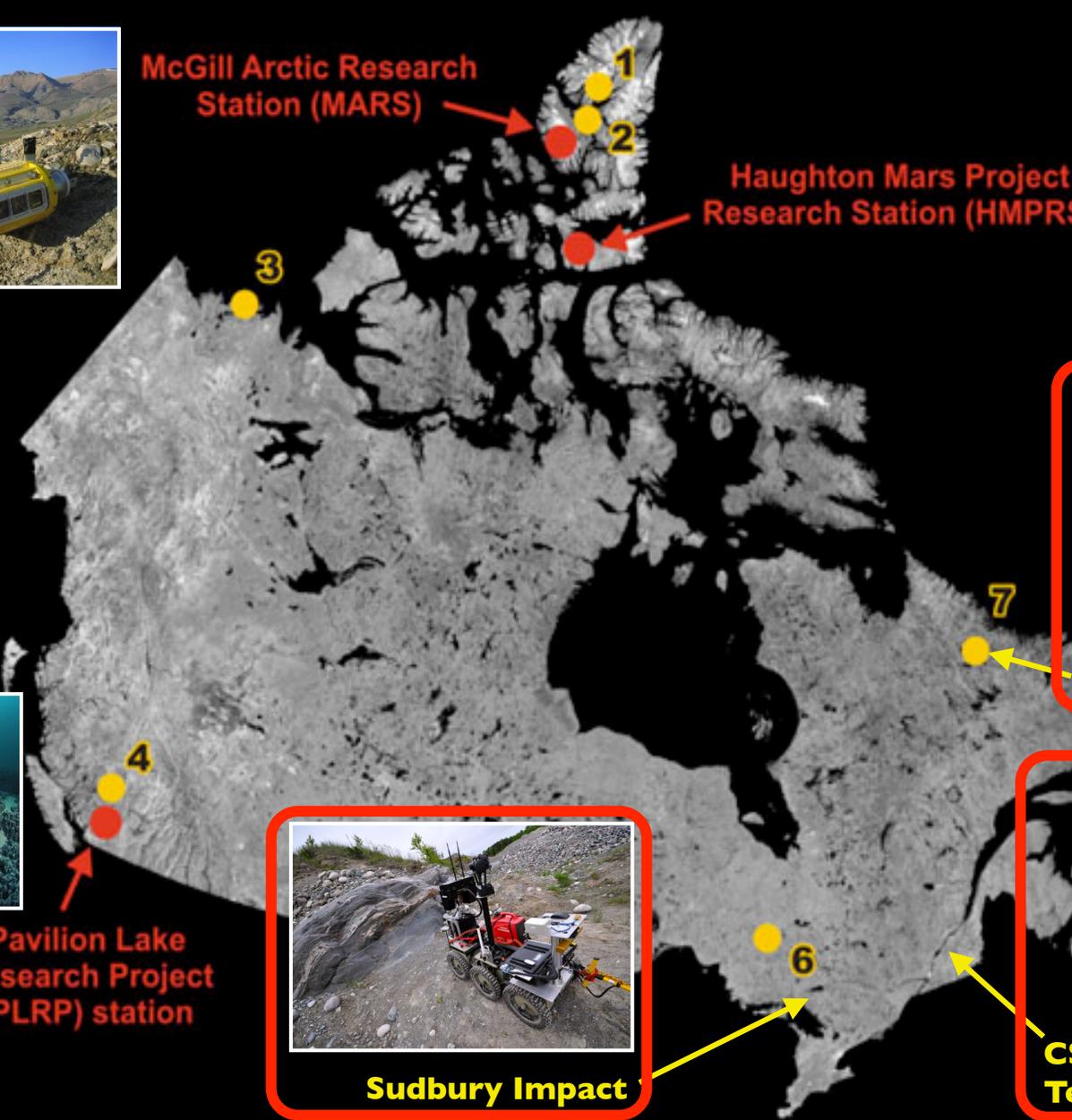
Some Recent Canadian Field Tests



McGill Arctic Research Station (MARS)



Houghton Mars Project Research Station (HMPRS)



Mistastin Lake Impact



Pavilion Lake Research Project (PLRP) station

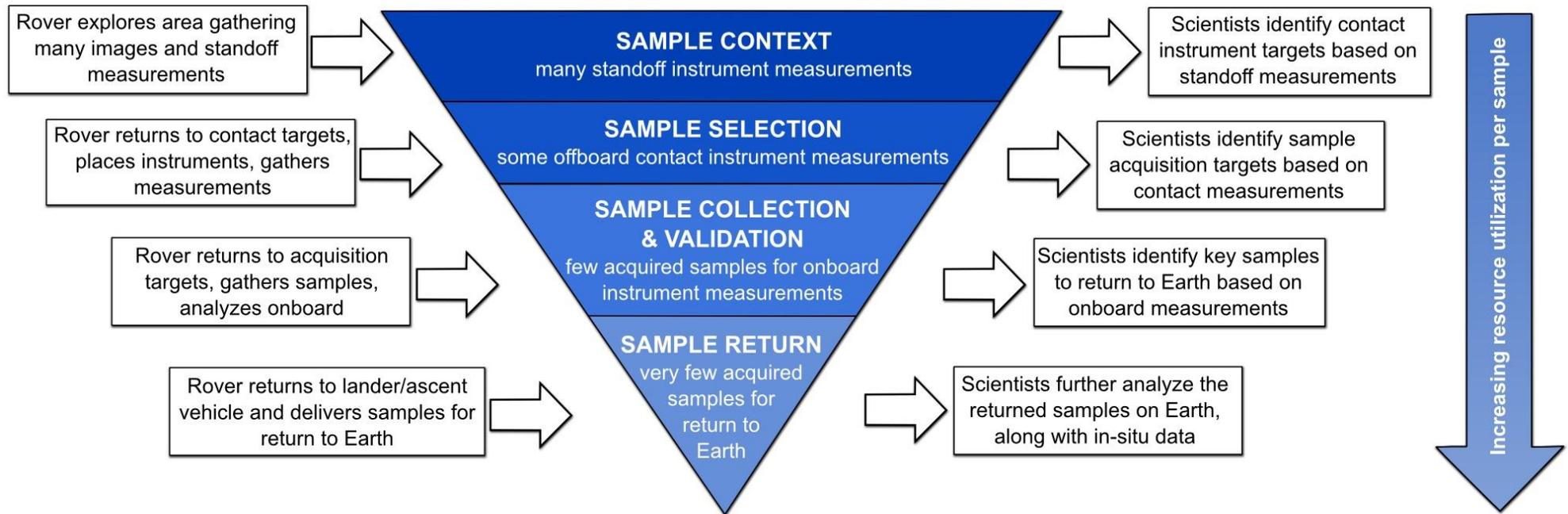


Sudbury Impact



CSA Mars Emulation Terrain

Sample Return Scenario



- we believe that a principled approach to sample return is a methodical down-sampling process
- the ability to revisit places is a key aspect of this
- NRP is one way we could implement this concept



Sudbury: Robot-Only Lunar Sample Return Scenario



Institute for Aerospace Studies
UNIVERSITY OF TORONTO



Guinevere outcrop (1 visit)

Arthur outcrop (4 visits)



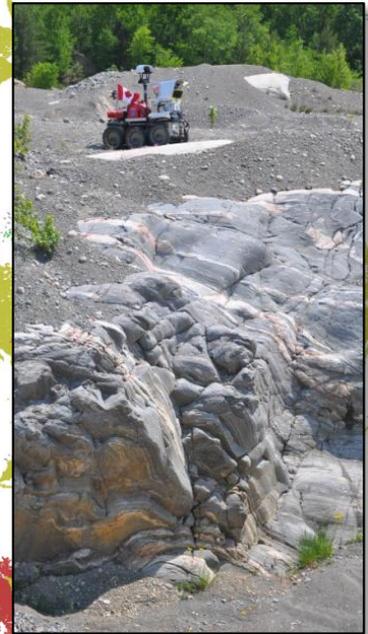
Merlin outcrop (3 visits)

The Round Table outcrop (2 visits)

Holy Grail outcrop (5 visits)

Lander (5 visits)

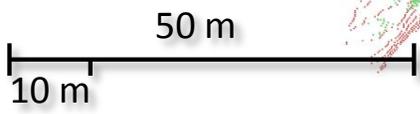
Percival outcrop (4 visits)



Black Knight boulder (2 visits)

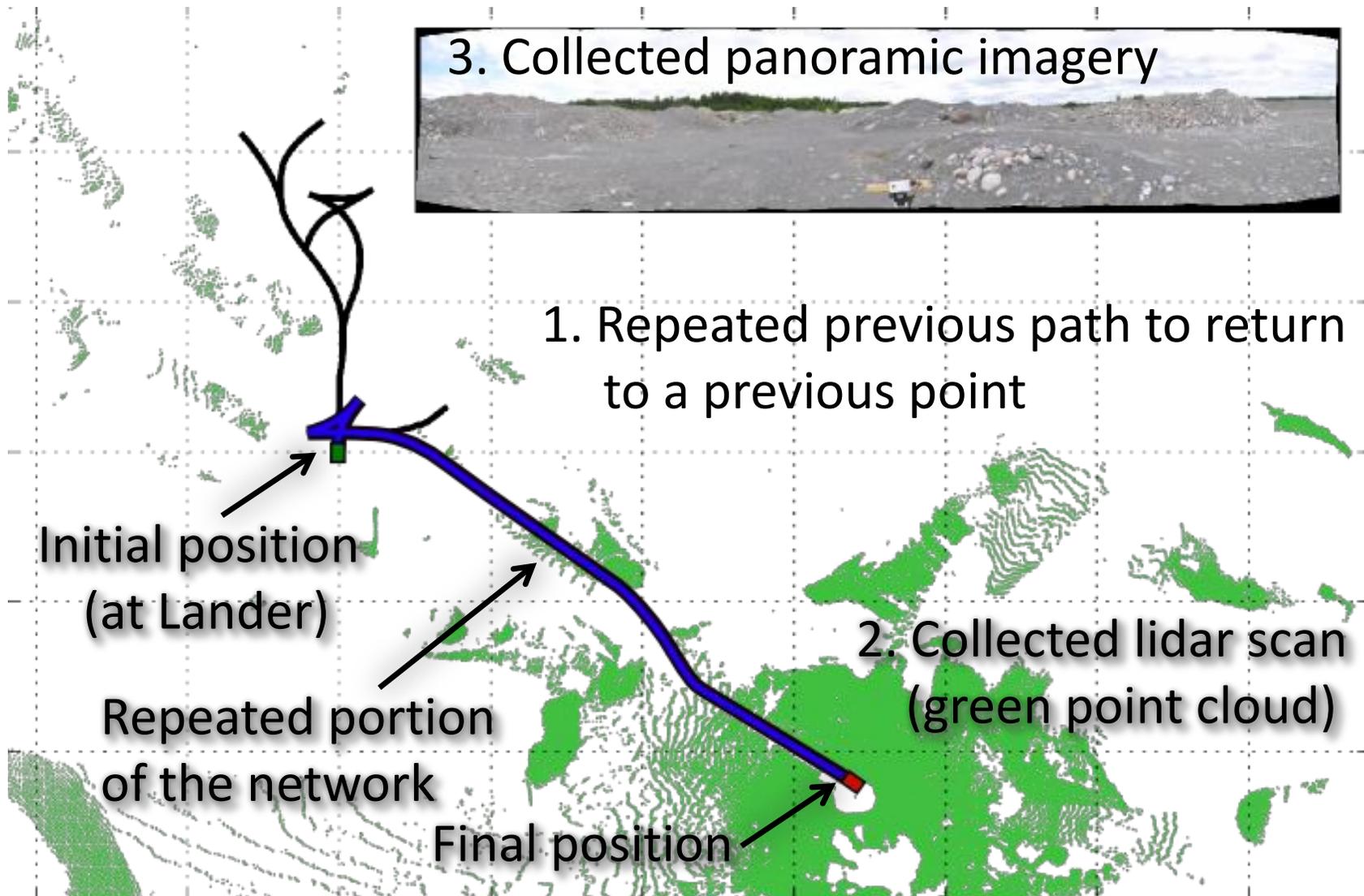
Pellinore outcrop (2 visits)

The Great Beyond (1 visit)

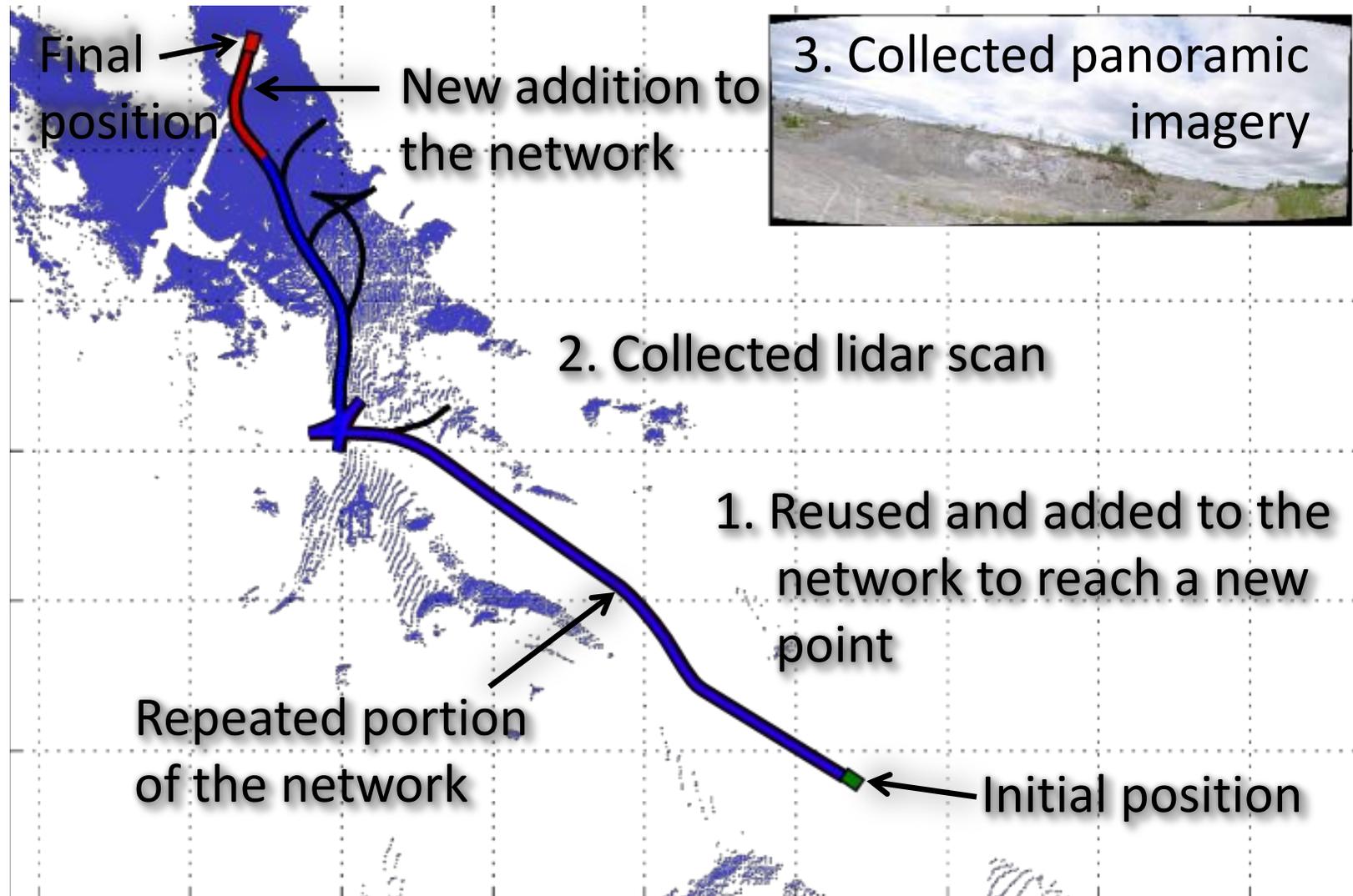


Sudbury 2011

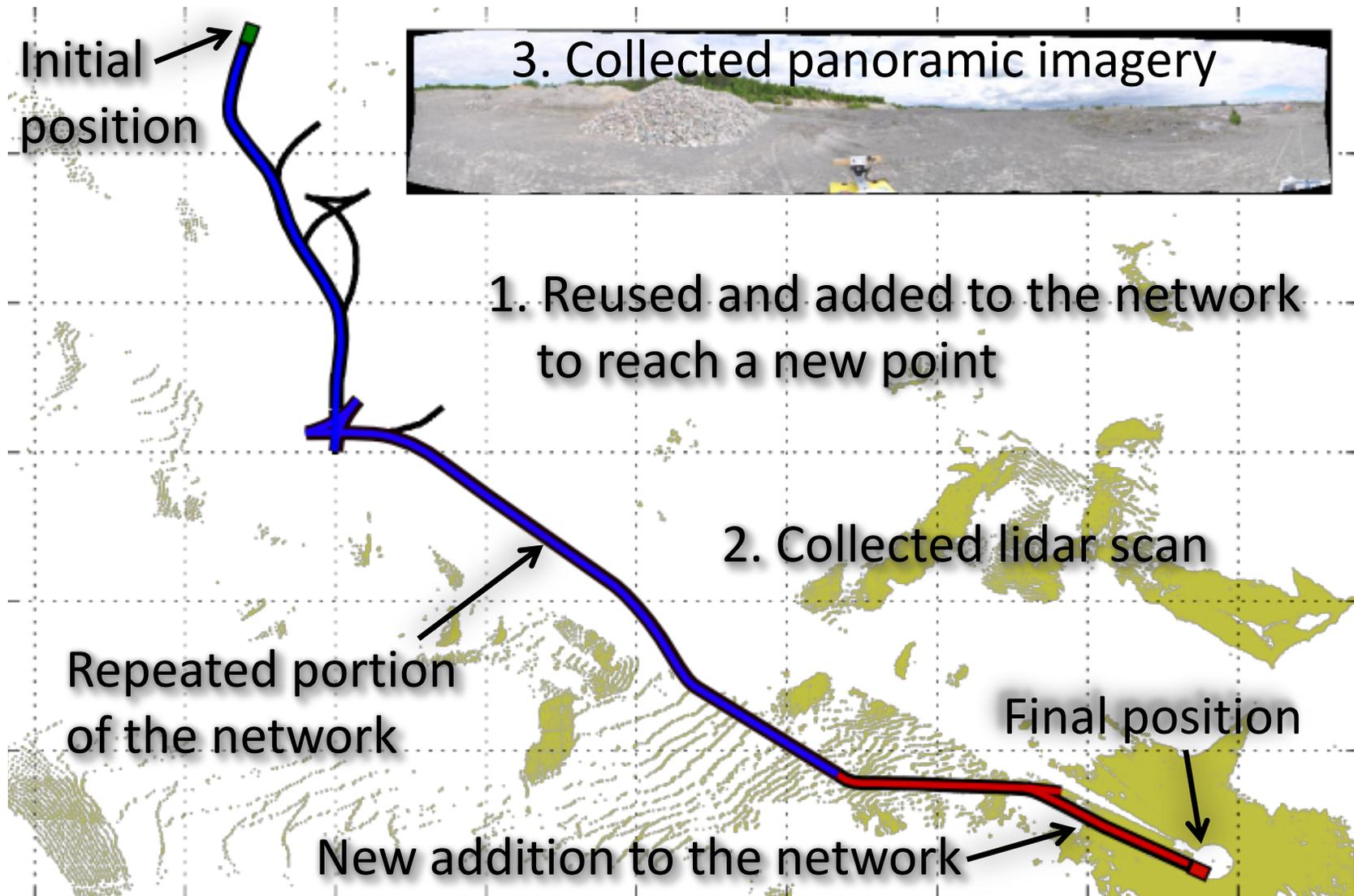
Sudbury: Week 2, Command Cycle 2



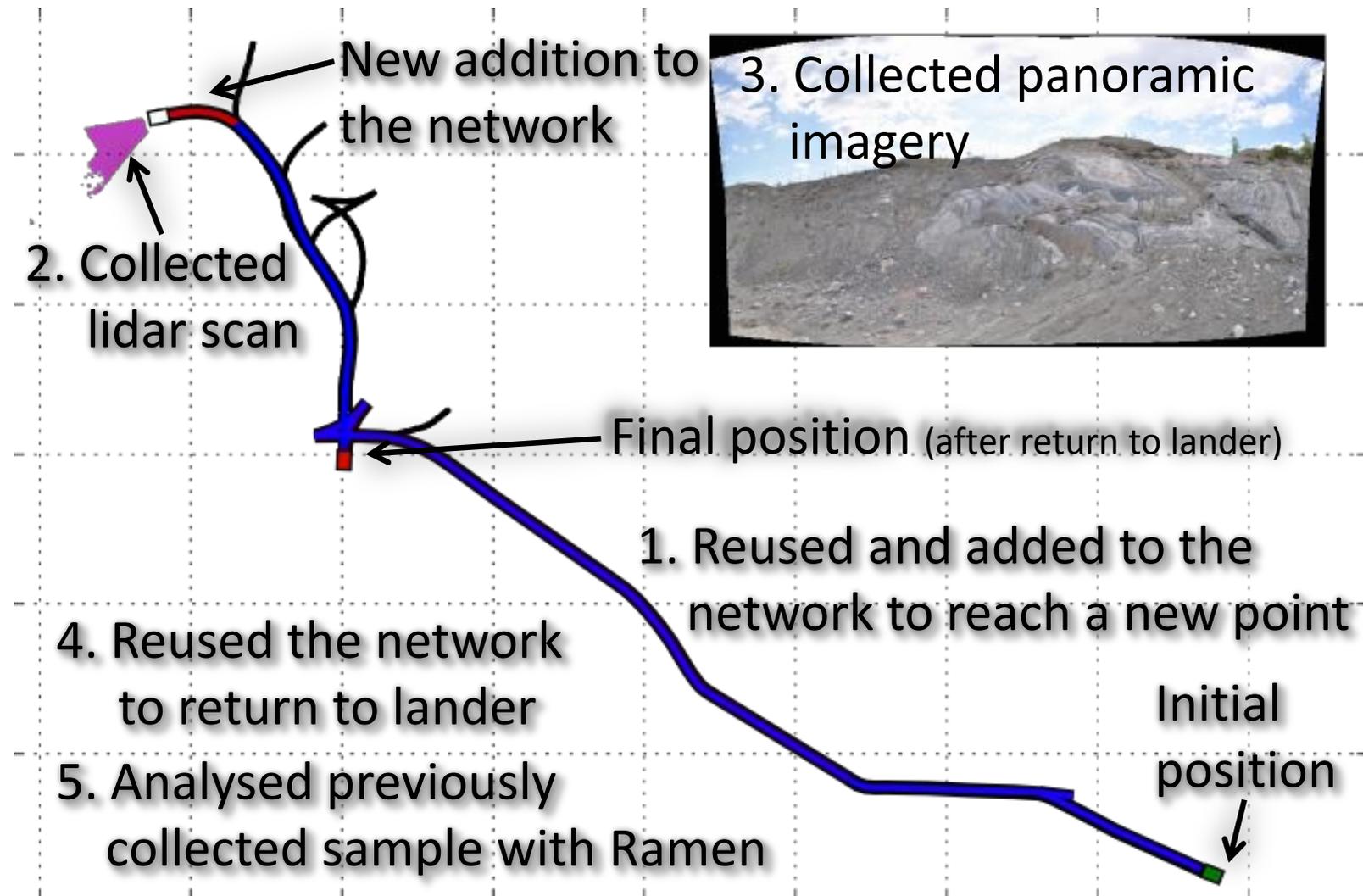
Sudbury: Week 2, Command Cycle 3



Sudbury: Week 2, Command Cycle 4



Sudbury: Week 2, Command Cycle 5



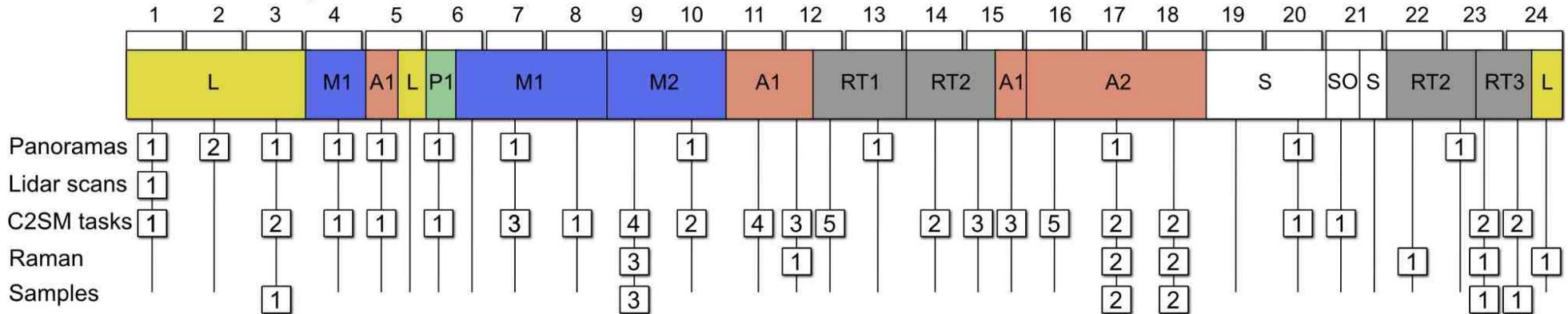
Sudbury: Sites Revisited Frequently

Sites of Interest

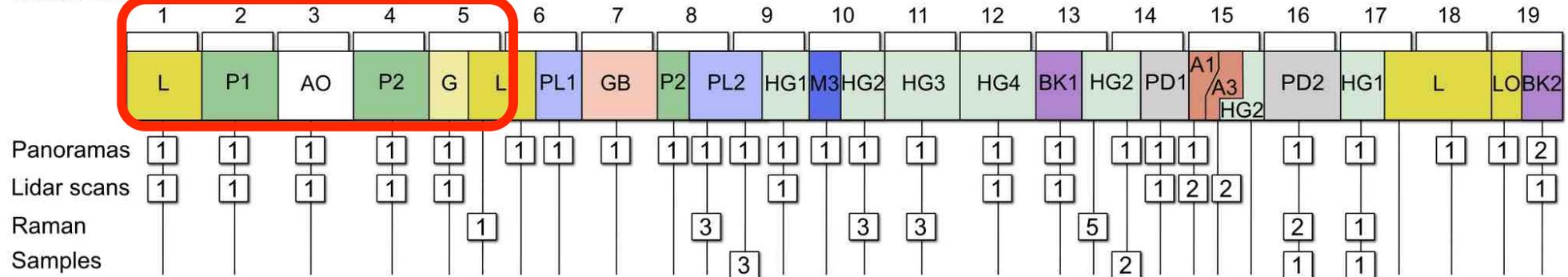
L - Lander	M - Merlin outcrop	A - Arthur outcrop	P - Percival outcrop	RT - The Round Table outcrop	S - Stuck site
LO - Lander observation site	G - Guinevere outcrop	PL - Pellinore outcrop	GB - The Great Beyond	HG - The Holy Grail outcrop	BK - The Black Knight boulder
				PD - Pendragon	SO - View of stuck site
					AO - Observation point near Arthur outcrop

Different poses that are at the same site are indicated by a number (e.g., M1 is the first pose that was visited at the Merlin outcrop).

Week One - Command Cycles



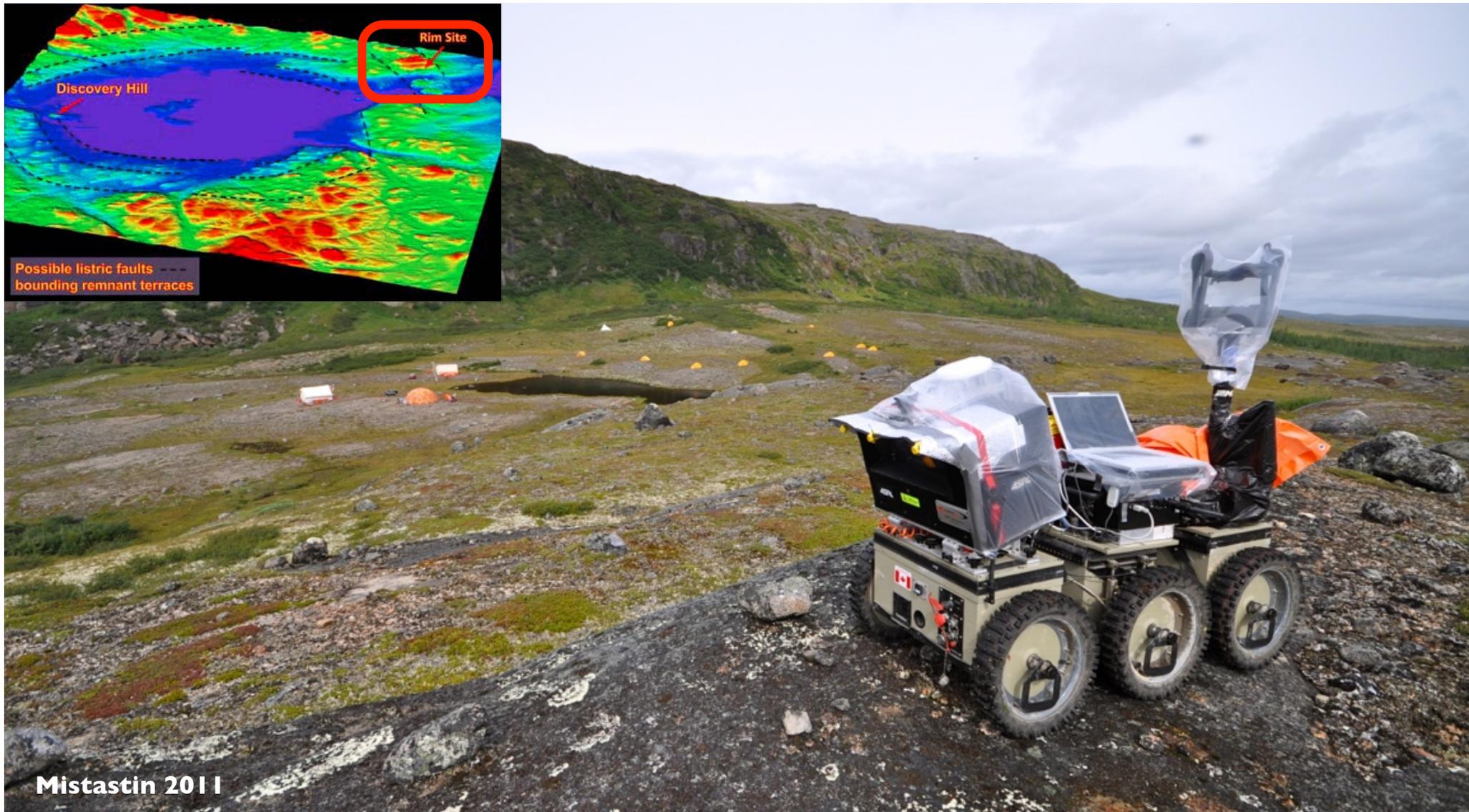
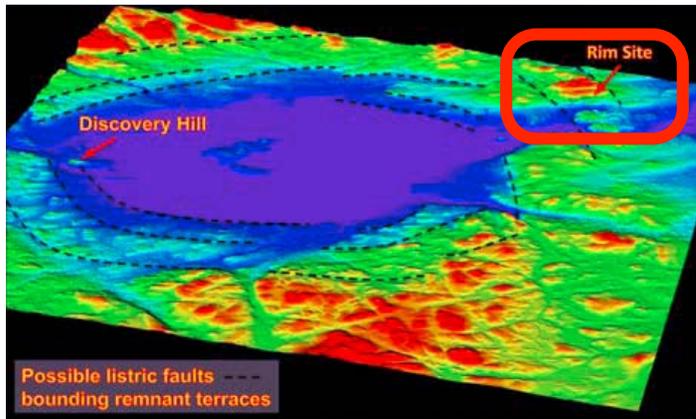
Week Two - Command Cycles



Sudbury: Samples Quite Varied in Small Area



Mistastin: Human-Robot Lunar Sample Return Scenario



Mistastin: Skycrane!



Institute for Aerospace Studies
UNIVERSITY OF TORONTO

Mistastin 2011



Mars 2012

Image: NASA/JPL/Caltech



Mistastin: Human Teaches Routes to Outcrops

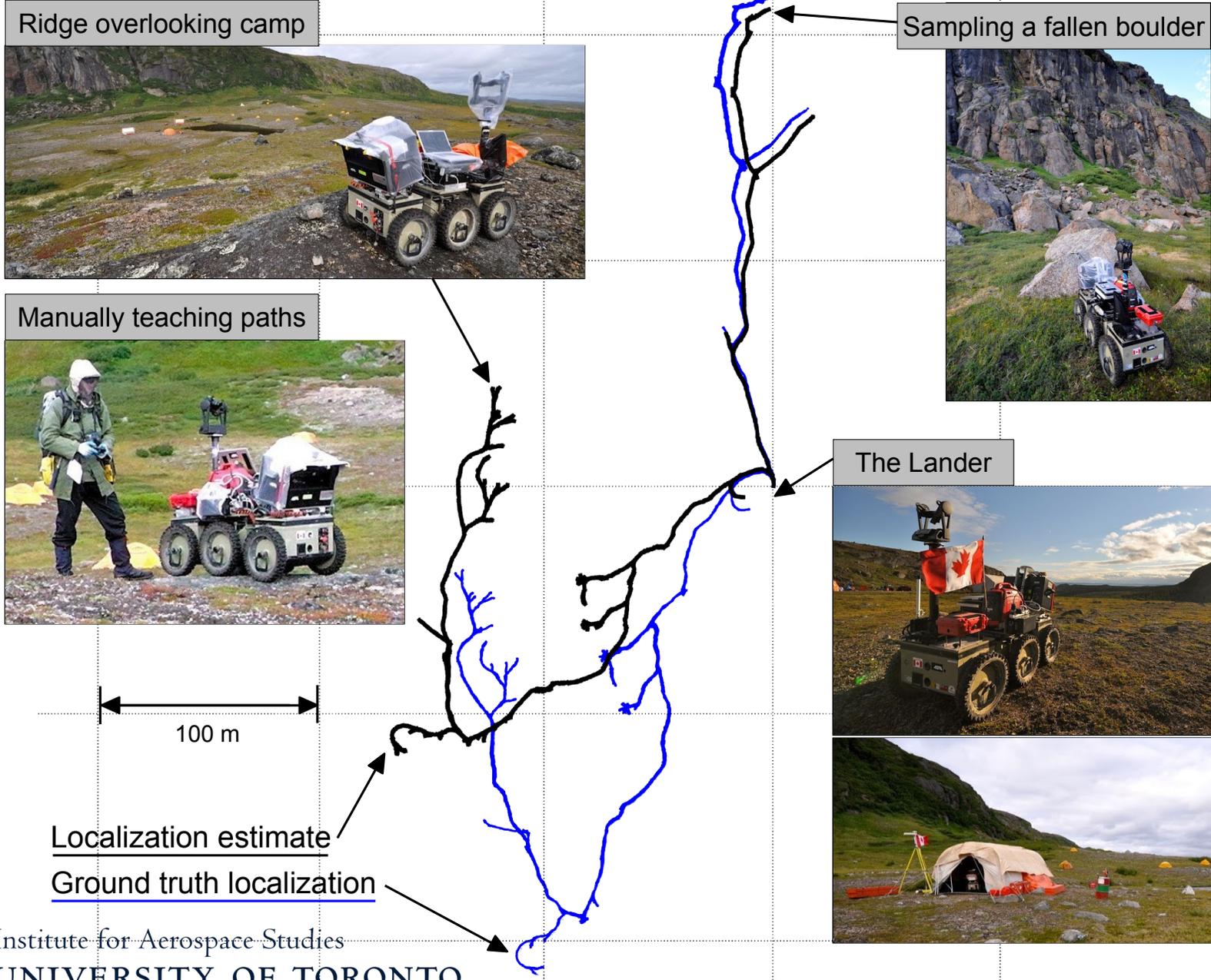
Mistastin 2011



Institute for Aerospace Studies
UNIVERSITY OF TORONTO



Mistastin: Network of Paths



CSA: Methane-Hunting Scenario

hidden methane source

signs

spectrometer

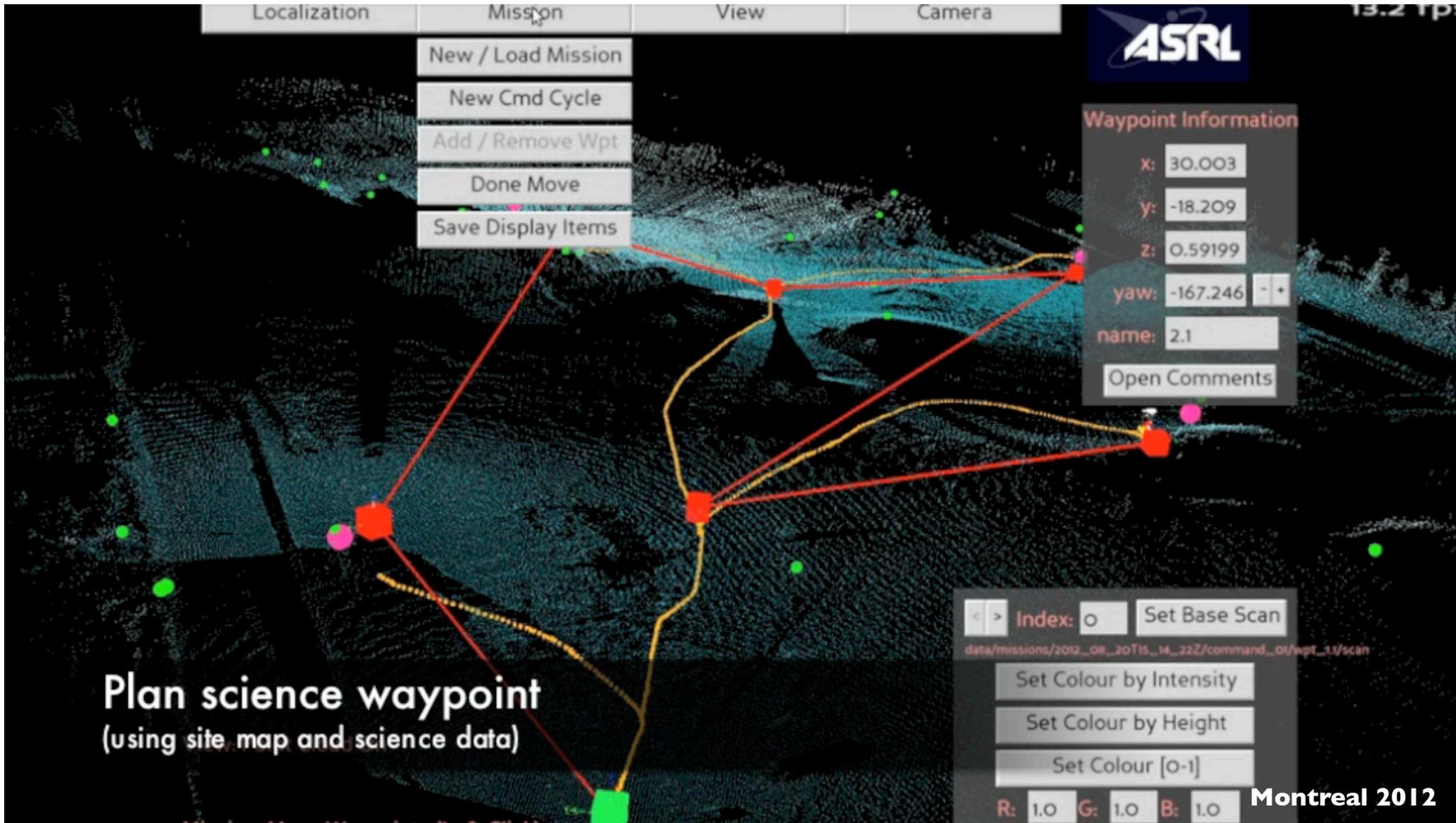
Montreal 2012



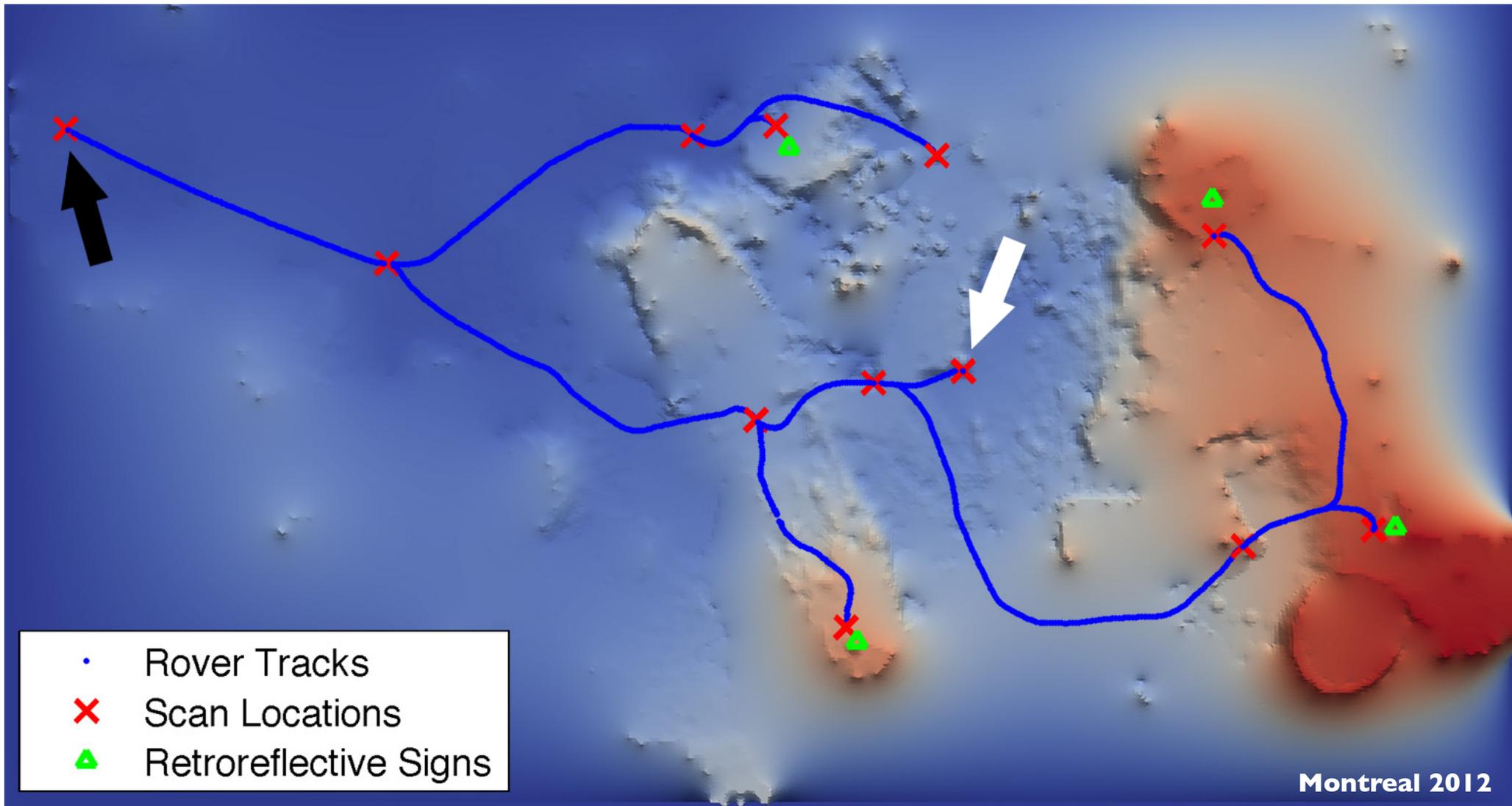
Institute for Aerospace Studies
UNIVERSITY OF TORONTO



CSA MET: Methane-Hunting Scenario



CSA MET: Network of Paths



Conclusion

- *networks of reusable paths* is a one navigation technology we can use to get the benefits of revisiting places by doing SLAM on the cheap
 - *roughly twice the cost of the usual VO pipeline*
- revisiting places opens up a wide variety of different mission scenarios that we might not have previously considered
 - parallel science investigations for methodical downselection of samples
 - human-robot exploration - e.g., robotic followup operations
 - biogas source localization



Future Work: Place Revisiting on Vertical Surfaces?

UTIAS 2013



Institute for Aerospace Studies
UNIVERSITY OF TORONTO



Thanks!



Questions?

Tim Barfoot

tim.barfoot@utoronto.ca

<http://asrl.utias.utoronto.ca>



Institute for Aerospace Studies
UNIVERSITY OF TORONTO

