Scheduling Targeted and Mapping Observations for the THEMIS Instrument onboard Mars Odyssey

Gregg Rabideau, Steve Chien, David Mclaren, Russell Knight
Jet Propulsion Laboratory, California Institute of Technology

Saadat Anwar, Greg Mehall, Philip Christensen
School of Earth and Space Exploration, Arizona State University

Space Operations Scheduling

- Produce a high level activity listing or a low level command sequence
- Achieving specified operations goals (science, or engineering)
- While respecting Operations constraints of the spacecraft
- Consistent with exogenous events (Orbit, uplinks, downlinks, visibilities, occultations, etc.)

Problem Definition

- Mapping Observations
  - Systematically cover a wide area of a planet under specified conditions (e.g. solar angle)
- Targeted Observations
  - Cover a small region under certain conditions (e.g. MSL landing site characterization, Olivene search)
- Operations Constraints
  - Limited onboard storage, instrument timing, uplink, downlink, etc.

Solution Definition

Given

a set of potential observation records $O = \{o_1 \ldots o_n\}$

a set of regions of interest $R = \{r_1 \ldots r_n\}$

a set of instrument swaths $I = \{i_1 \ldots i_n\}$

Where $\forall\, o_i \in O\ \exists(r_i, i_i)\ grid(o_i) \in grid(r_i) \wedge grid(o_i) \in grid(i_i)$

a scoring function $U(r_i) \rightarrow$ real

a constraint function $C(S) \rightarrow T,F$

where $S \subseteq O$ and C is True if S satisfies spacecraft constraints

Select a set of observations A

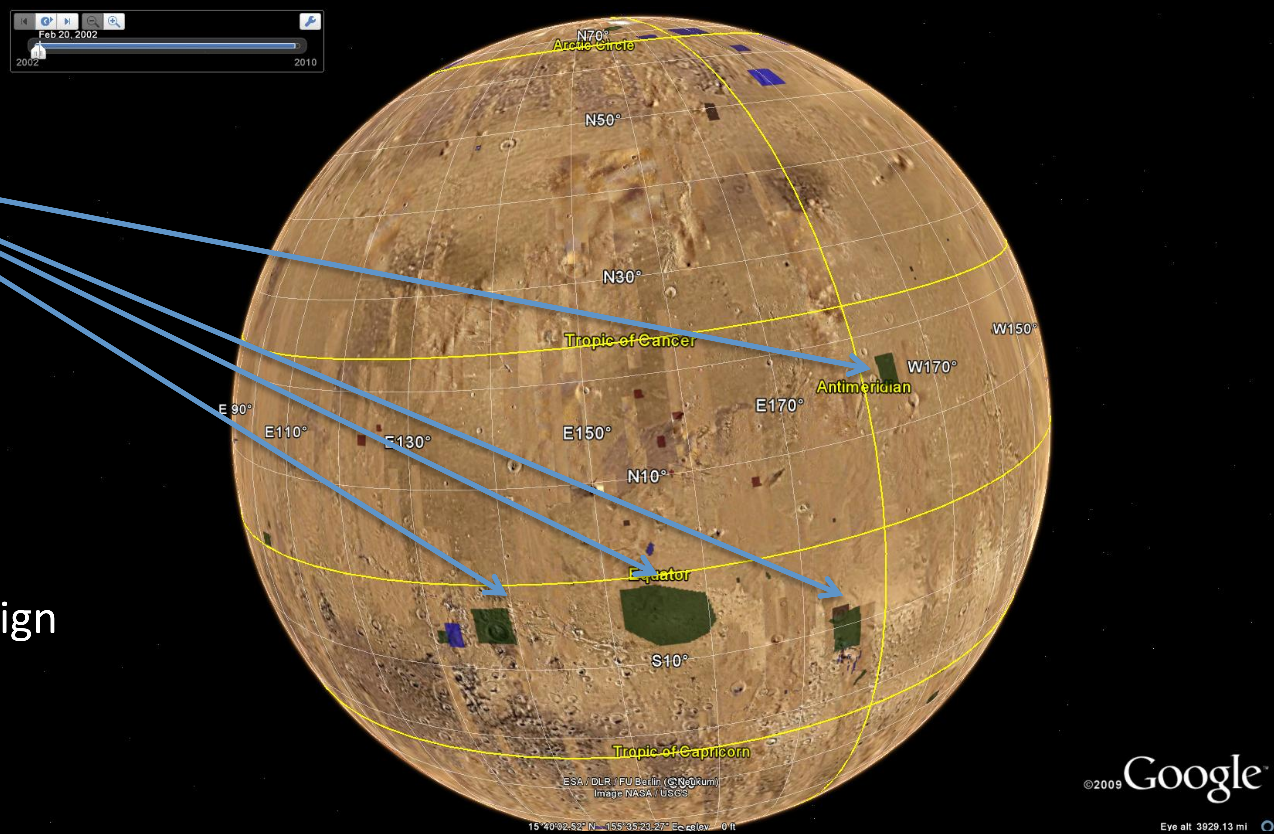
To maximize $\Sigma_{a \in A} U(a)$ subject to $C(A) \rightarrow T$

Spatial Coverage

- Grid representation
  - Overlap is considered by common points on a grid
- Makes schedule maximization problem
  - Individual candidate observations receive credit for covering grid points of regions of interest (or mapping areas)
  - Goal is to select observations to maximize spatial coverage score

Example ROI Representation

Regions for Campaign 1

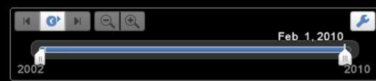


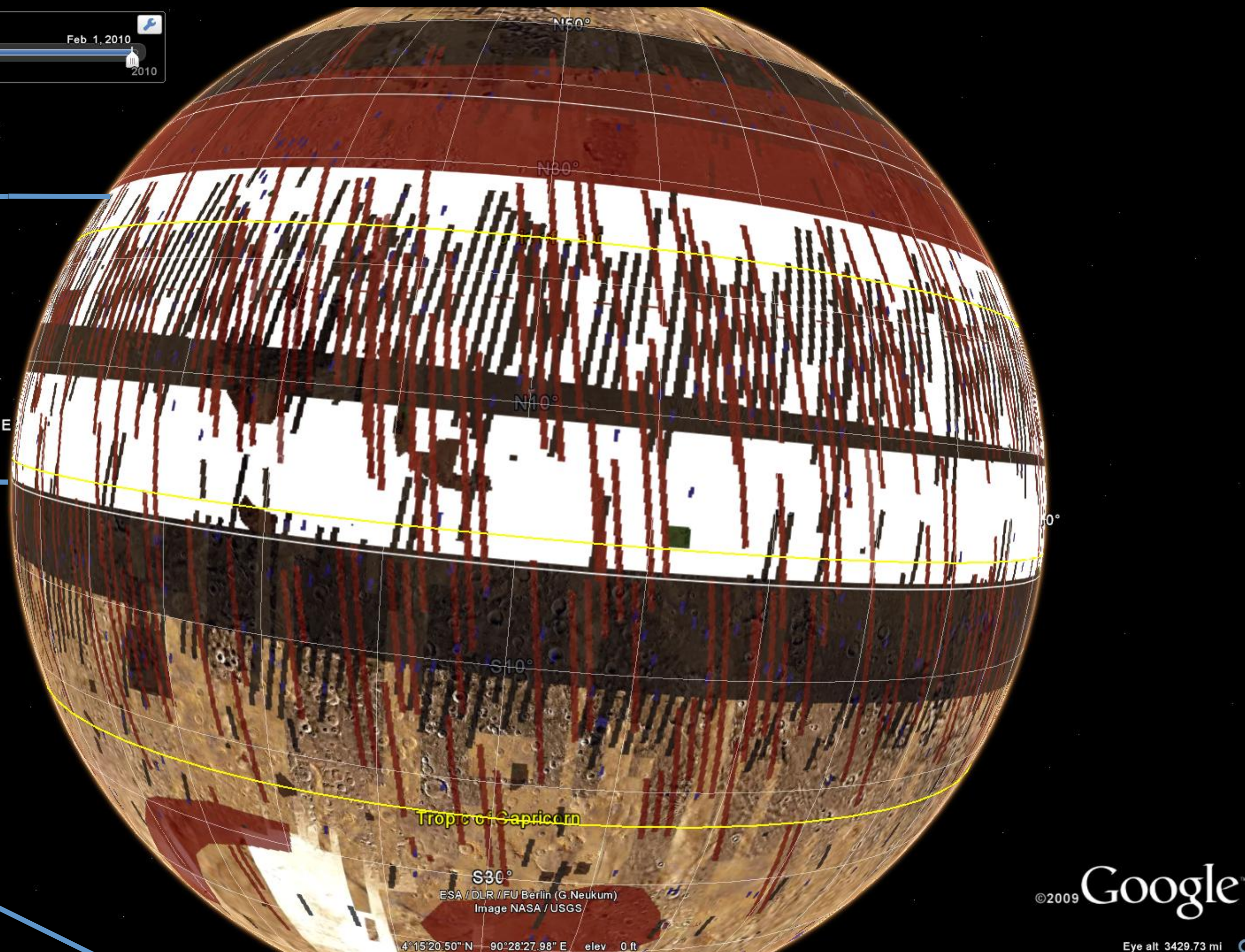
ROI Science Campaign

or

Polygon12 Polygon14 Polygon16 Polygon18

Example Mapping





Region around subsolar point

Mapping Campaign

and

Subsolar region

not

Area of science interest

O_1-Poly

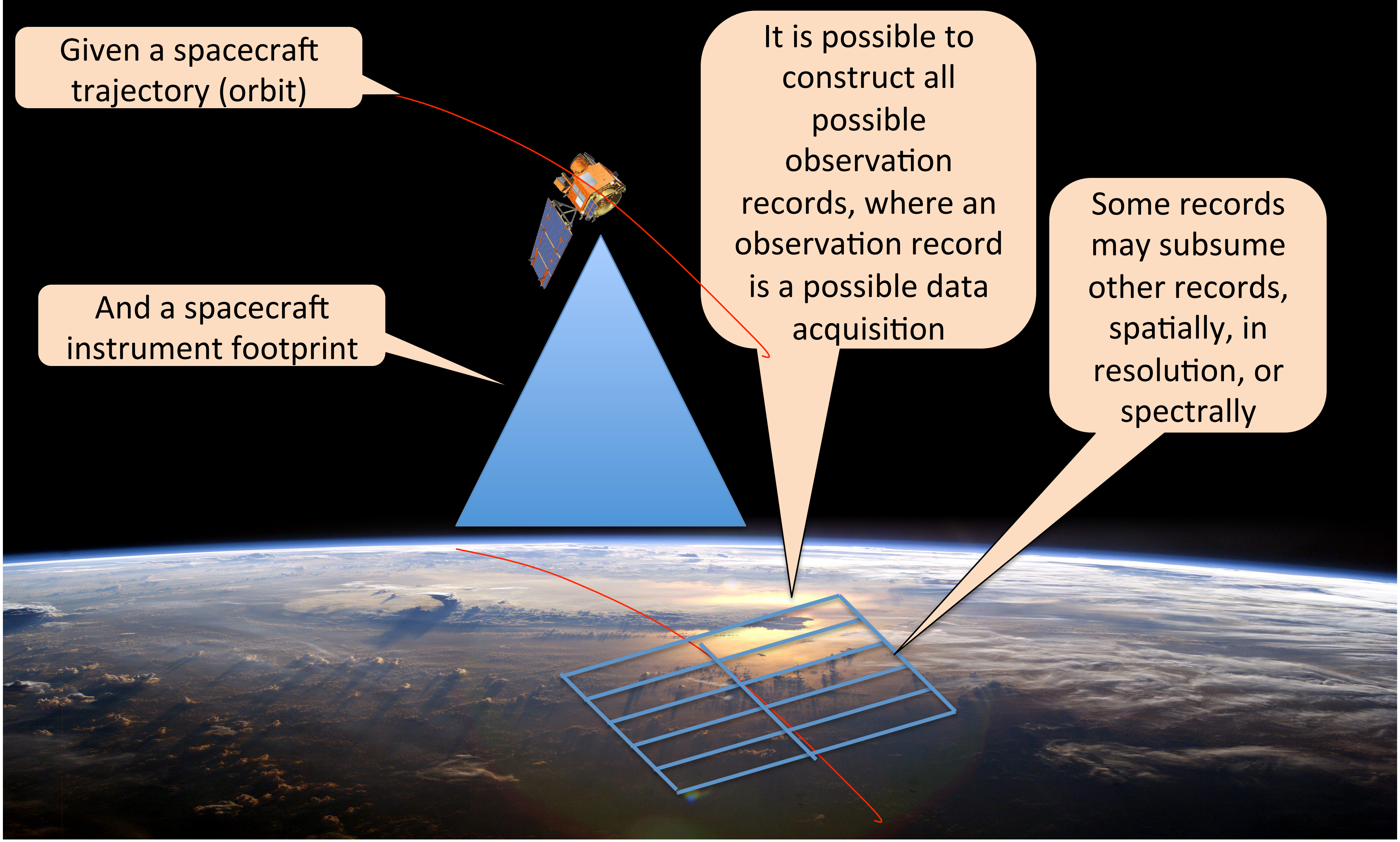
O_2-Poly

O_3-Poly

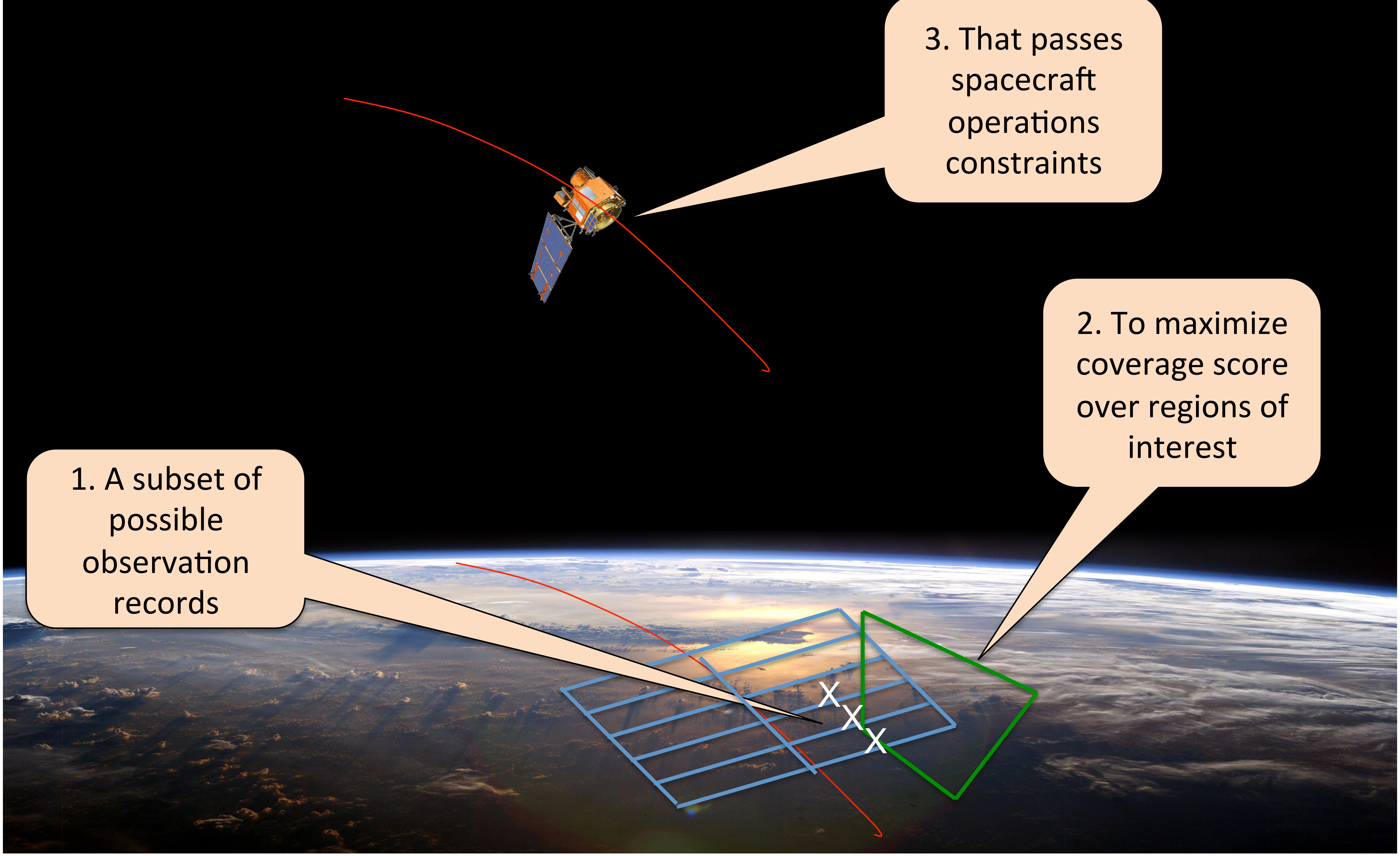
O_n-Poly

Excluding areas already covered

Observation Records



Solution Definition



Approach – Generate & Test

- Add/Change Observations
  - Increase score
- Evaluate Constraints
- Accept if feasible
- Continue until cannot add any further
- Squeaky wheel

THEMIS / ODY Mission

- THEMIS is the principal Instrument on the Odyssey mission
- THEMIS has Infrared (IR) and Visible imaging capability

THEMIS Observation Selection

- Select observations to maximize
    - Targeted (region of interest) score
    - Mapping score

- While respecting operations constraints
    - Observation spacing
    - Observation length
    - Onboard Storage
    - Command buffer

THEMIS SWO Algorithm

- Initialize observation priority to science campaign score
- Sort candidate observations by decreasing priority
- Add each observation
  - Add observations implied by addition
  - New plan consistent with operations constraints
    - TRUE – return to add step
    - FALSE – remove observation, return to add step
- Done when no more observations to consider

- Save schedule if best so far
- Increase the priority of all observations not getting into schedule

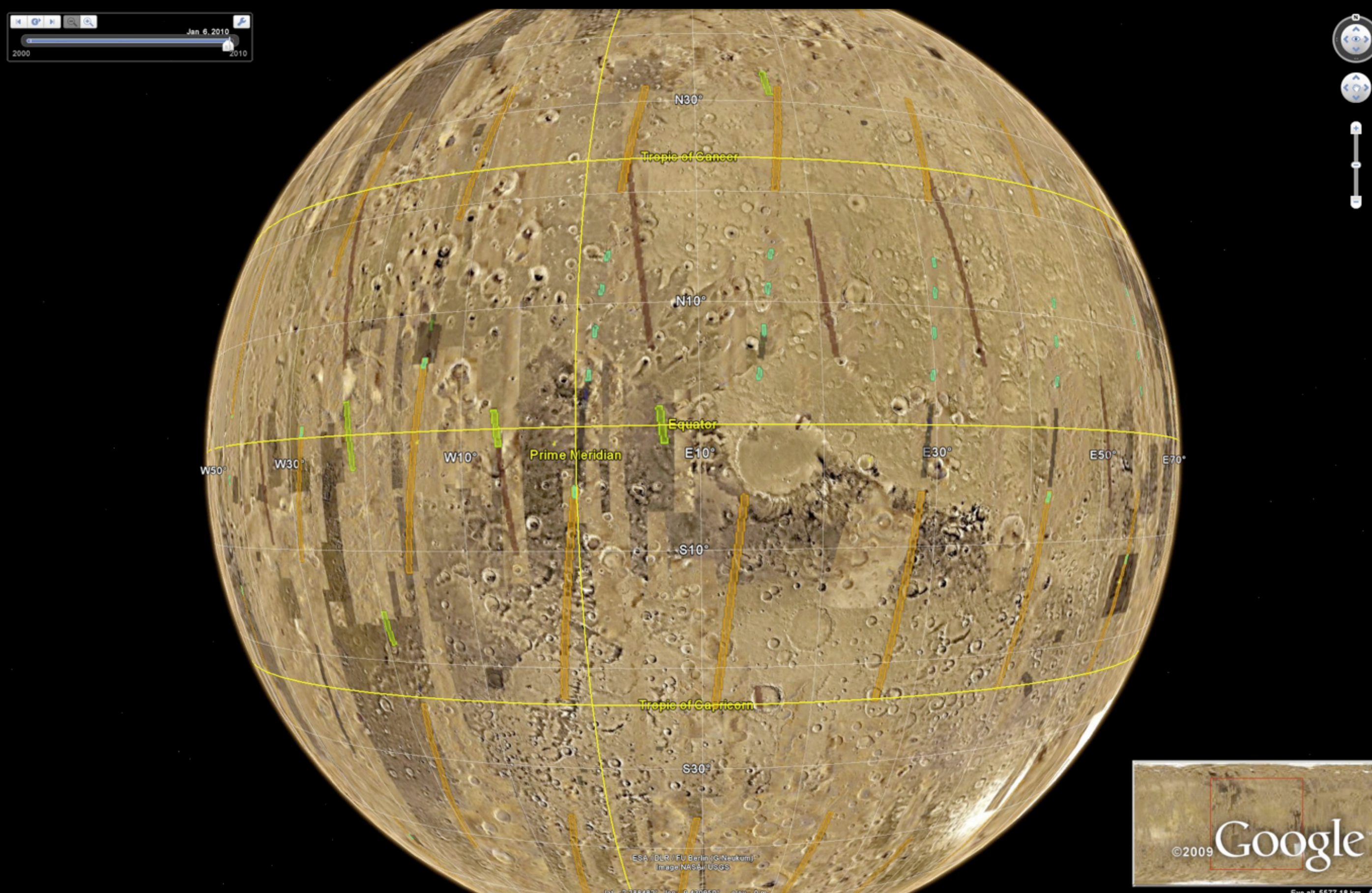
THEMIS Context

- Practically speaking, THEMIS science planners work on two schedules per week, each of 3-4 Earth days at a time.
  - Because of the automation, there is interest in constructing scheduled of 7 days for analysis purposes and CLASP-TOST has been tested on a one week planning horizon.

THEMIS Context

- Each day of schedule translates into hundreds of thousands of map grid points that must be evaluated.
- On-board storage for science data is the primary factor limiting the THEMIS observation volume, allowing only a few hours of observation time each day.

Sample Schedule



THEMIS Results

- Below we show the runtime performance of CLASP-TOST on a four and seven day schedules
  - 64 bit Red Hat Linux, dual core 2.4GHz AMD Opteron, 16GB RAM, -O2 optimization

Schedule Duration	4 Earth Days	7 Earth Days
# of observations in generated schedule	421	758
Time to generate instrument Swaths	~2 minutes	~3 minutes
Time to generate science ROI's	~2 minutes	~2 minutes
CLASP - Initialization	~10 minutes	~20 minutes
CLASP # of iterations, time per iteration	3 x ~15.5. minutes	3 x ~83 minutes
Total CLASP Time	56 minutes	4 hours and 31 minutes

Status

- TOST not accepted for operational use for THEMIS
  - Manual scheduling allows for greater tailoring of observation campaigns
- Coverage analysis capability has been used for numerous mission studies
  - Enables missions in concept phase to better understand how mission design, spacecraft design, operations concept affects mission return

Related Work

- Relatively little work in spatial coverage planning
- Exceptions include CLASP for DesdynI planning
- Considerable other work in space operations planning for HST, MAMM, Orbital Express, EO-1, Mars Express, Space Shuttle, and others

Future Work

- Implementation of alternative optimization methods and comparison of these to SWO
- Investigate methods of rewarding "regularity" in coverage patterns (in mapping).
- Considering non linear / interdependent scoring functions

Conclusions

- Spatial coverage aspects can be represented as optimization by quantization of coverage/overlap
- Oversubscribed schedule optimization problem can then be attacked using a wide range of techniques
- We present use of squeaky wheel optimization to solve such a problem
- We present the application of these techniques to observation selection for the Mars Odyssey THEMIS Instrument