Optimal Attitude Guidance for the EXACT and IMPRESS Cubesats using Graph Methods with Pruning

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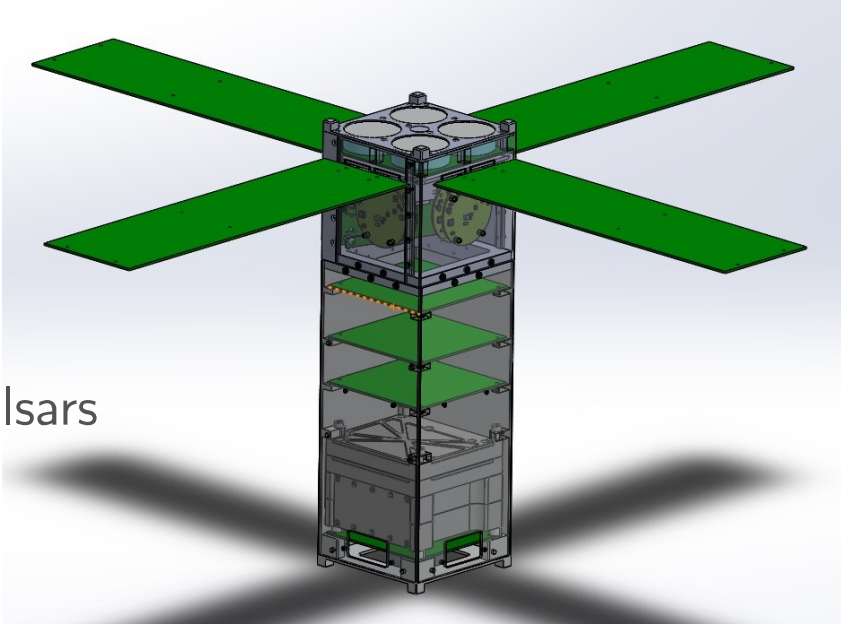
Two scientific cubesats

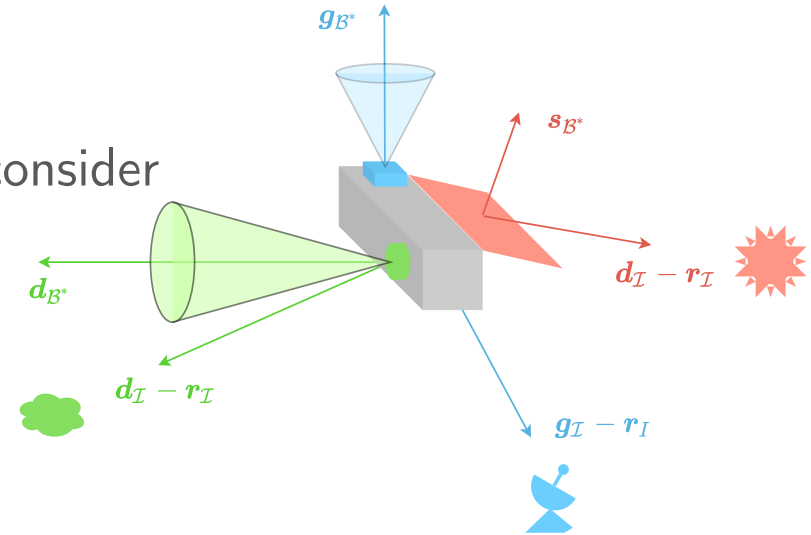
- **EXACT:**
  - Deep-space navigation with x-ray pulsars
  - X-ray detector payload
- **IMPRESS:**
  - Solar physics mission
  - Same detector payload
- **Both have a detector, solar panels, and radio that have pointing requirements**



Model of IMPRESS/EXACT

Motivating an attitude guidance problem

- At a given time, there may be **many** reasonable attitudes for a satellite.
- Attitude history affects the decision
  - battery level, onboard data
- There is an overall mission objective to consider



Mission planning problem

- Assume a mission in which we wish to **transmit as much data** to the ground (G) as possible by the end
- Also, battery level E should not be depleted

$$\max_{\boldsymbol{C}_{\mathcal{BI}}(i)\ \forall i\in\{0,\ldots,N\}} \quad G(N)$$

$$\text{subject to}$$

$$\boldsymbol{x}(i+1) = \boldsymbol{f}_k\big(i, \boldsymbol{x}(i)\big) \qquad \forall i \in \{0, ..., N\}$$

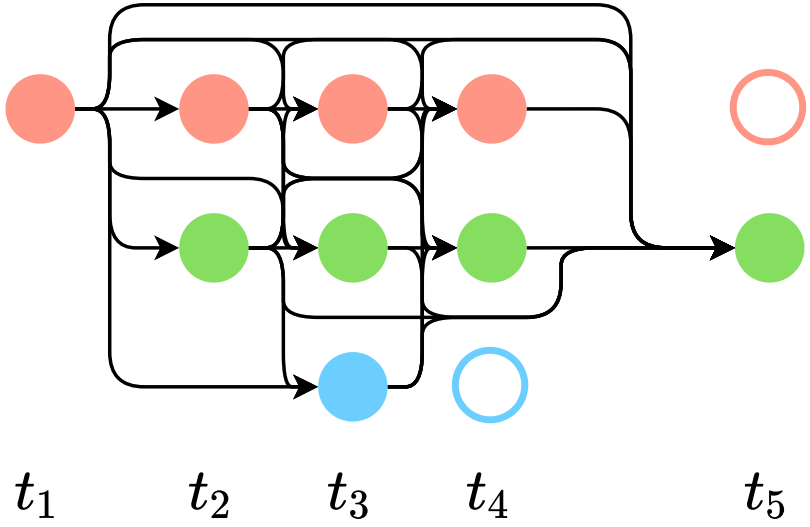
$$E(i) > E_{min} \qquad \forall i \in \{0, ..., N\}$$

Prior work

- **Integer programming/graph methods:**
  - M. Lemaître et al. 2002, J. F. Cordeau et al. 2005, S. Spangelo et al. 2015, Y. She et al. 2018
- **Optimal control:**
  - B. Wie et al. 2002, J.T. Hwang et al. 2014, W. Qiu and C. Xu 2020

Graph introduction

- Want to work towards a graph-based formulation
- Nodes contain information, edges define transitions



Modeling the satellite

- State:

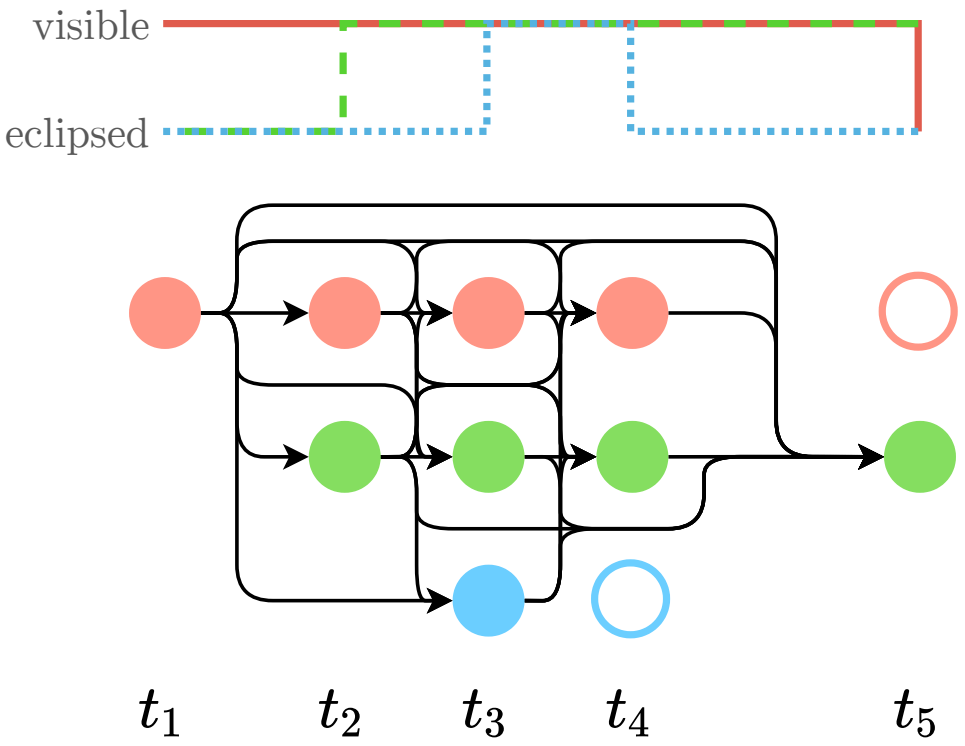
$$\boldsymbol{x} = \begin{bmatrix} \mathrm{vec}(\boldsymbol{C}_{BI}) \\ E \\ S \\ G \end{bmatrix}$$

Attitude
Battery level
Data volume stored onboard
Data volume downlinked

- Attitude is directly chosen at each discrete time step
- $E,\ S,\ G$ are propagated with discrete dynamics

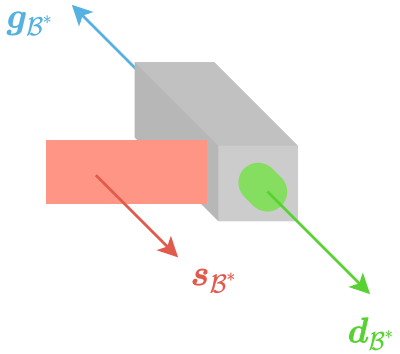
Graph and paths

- Know orbit, target visibility *a priori*
- Once the nodes and edge rules are defined, can form a **graph:**
- Each **path** through this graph yields a specific history of battery level and downlinked data



Case studies for IMPRESS and EXACT

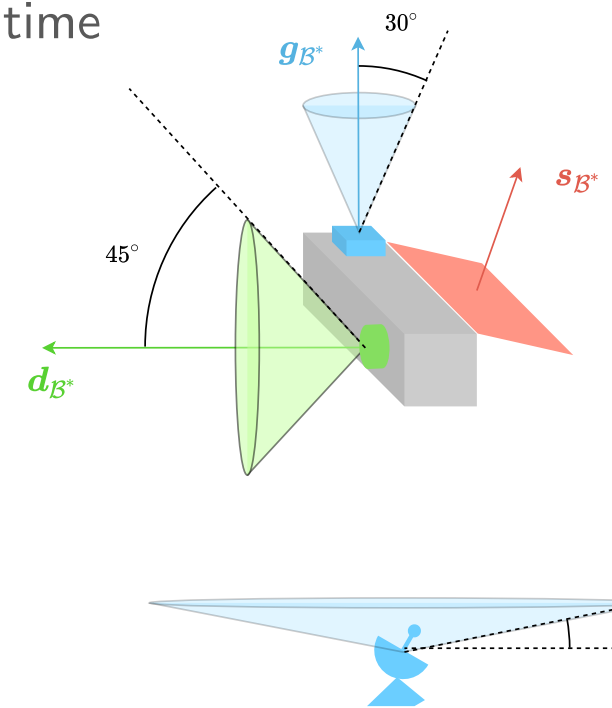
- ISS orbit: circular 400 km, 55º inclination
- Targets:
  - Sun
  - Sun (IMPRESS)/Crab Nebula (EXACT)
  - Ash River, MN; Vandenberg AFB, CA; Kihei, HI; Gainesville, FL; College Station, TX



Case studies for IMPRESS and EXACT

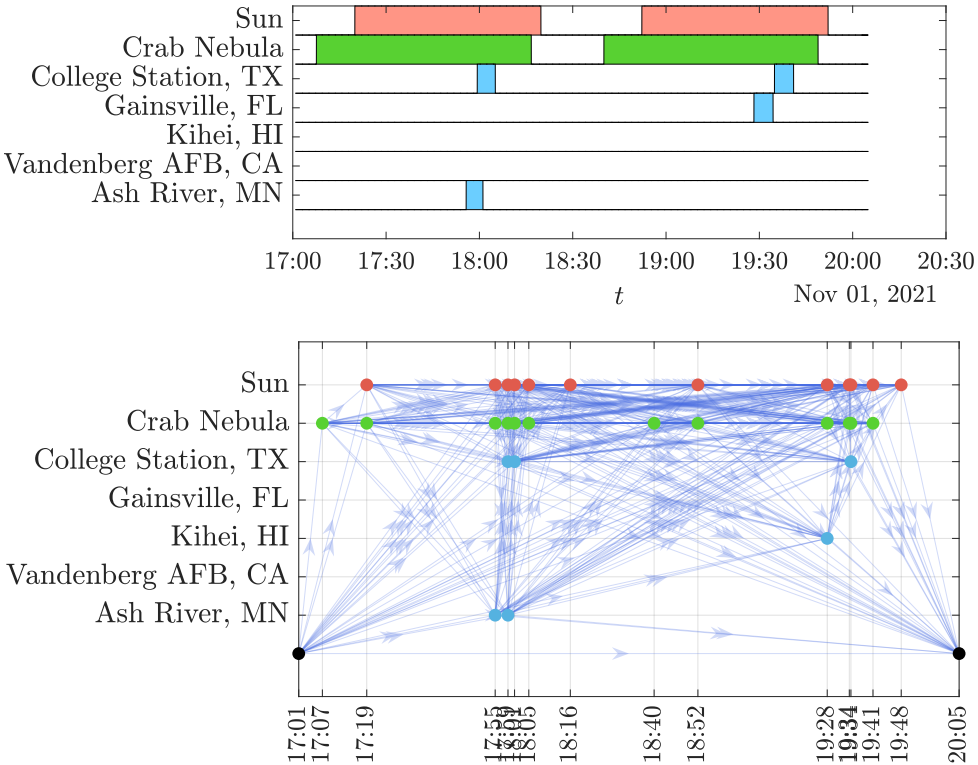
- Two orbits simulated with arbitrary starting time

Parameter	Value	Unit
Battery minimum	30	W Hr
Battery maximum	40	W Hr
Groundstation elevation mask	5	deg
Radio pointing requirement	30	deg
Detector pointing requirement	45	deg

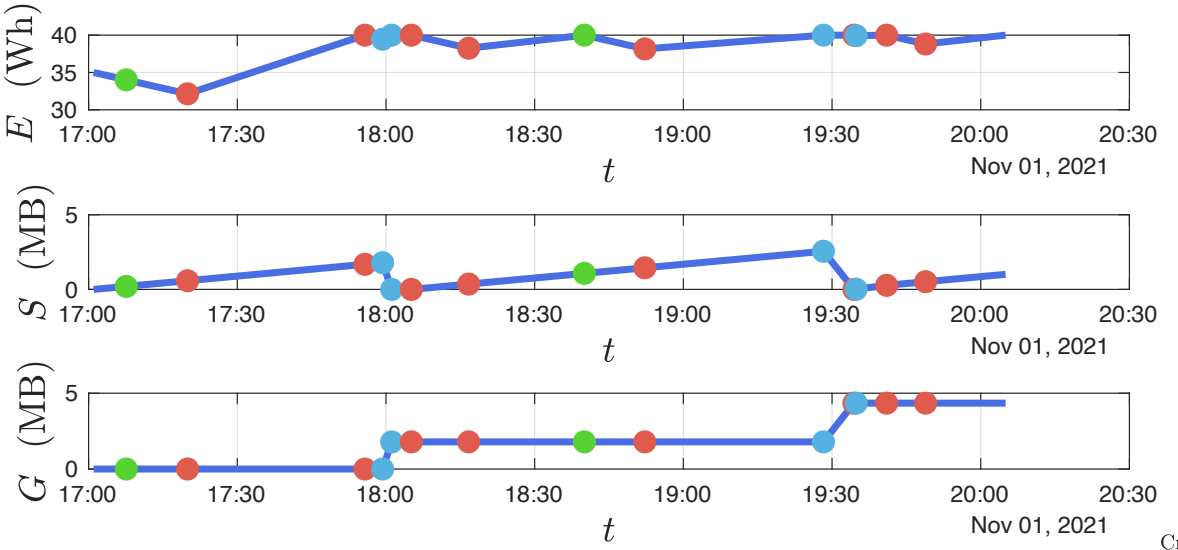


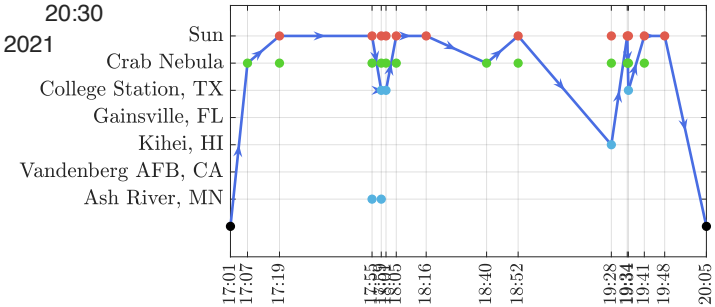
Results

- Hardware: 1.3 GHz Intel i3, 8GB RAM
- 13 opportunities for maneuver based on time discretization criteria
  - 4,976,639 possible attitude sequences
- Takes ~2 minutes to solve

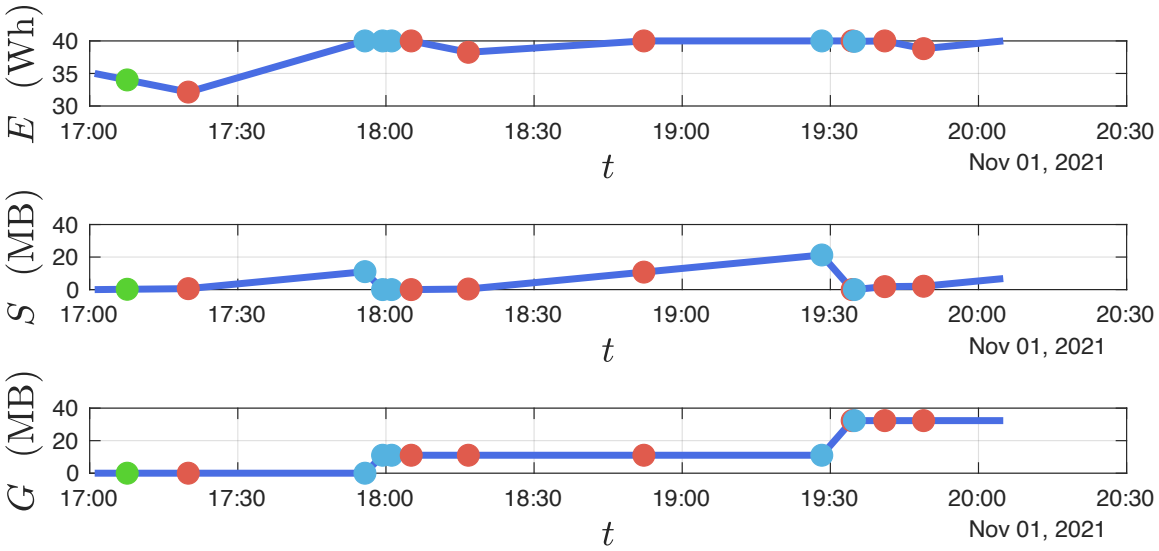


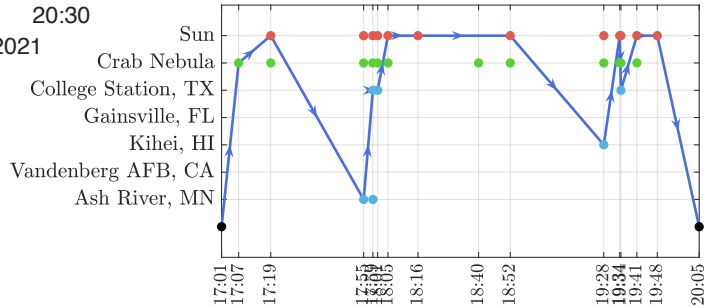
Results—EXACT





Results—IMPRESS





Conclusions

- Graph method is successful for short horizons, fast actuators
  - could be extended to slow actuators
  - fundamental scaling problem

Acknowledgements

Coauthor Demoz Gebre-Egziabher

UMN Small Satellite Research Lab

Thank you

- Questions:
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