Scheduling Science Campaigns for the Rosetta Mission: A Preliminary Report

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Background

- Rosetta is an ESA cornerstone mission
- Rosetta will reach the comet 67P/Churyumov-Gerasimenko in 2014 and will
  - Deploy Philae Lander
  - Escort the comet for ~ 9 months
- Rosetta will conduct the most detailed study of a comet ever undertaken by humankind.
- The Rosetta orbiter has:
  - 11 scientific instruments (4 remote sensing) and
  - the Philae lander

  to make complementary measurements of the comet nucleus, coma (gas and dust), and surrounding environment.

Rosetta Science Ground Segment (SGS)

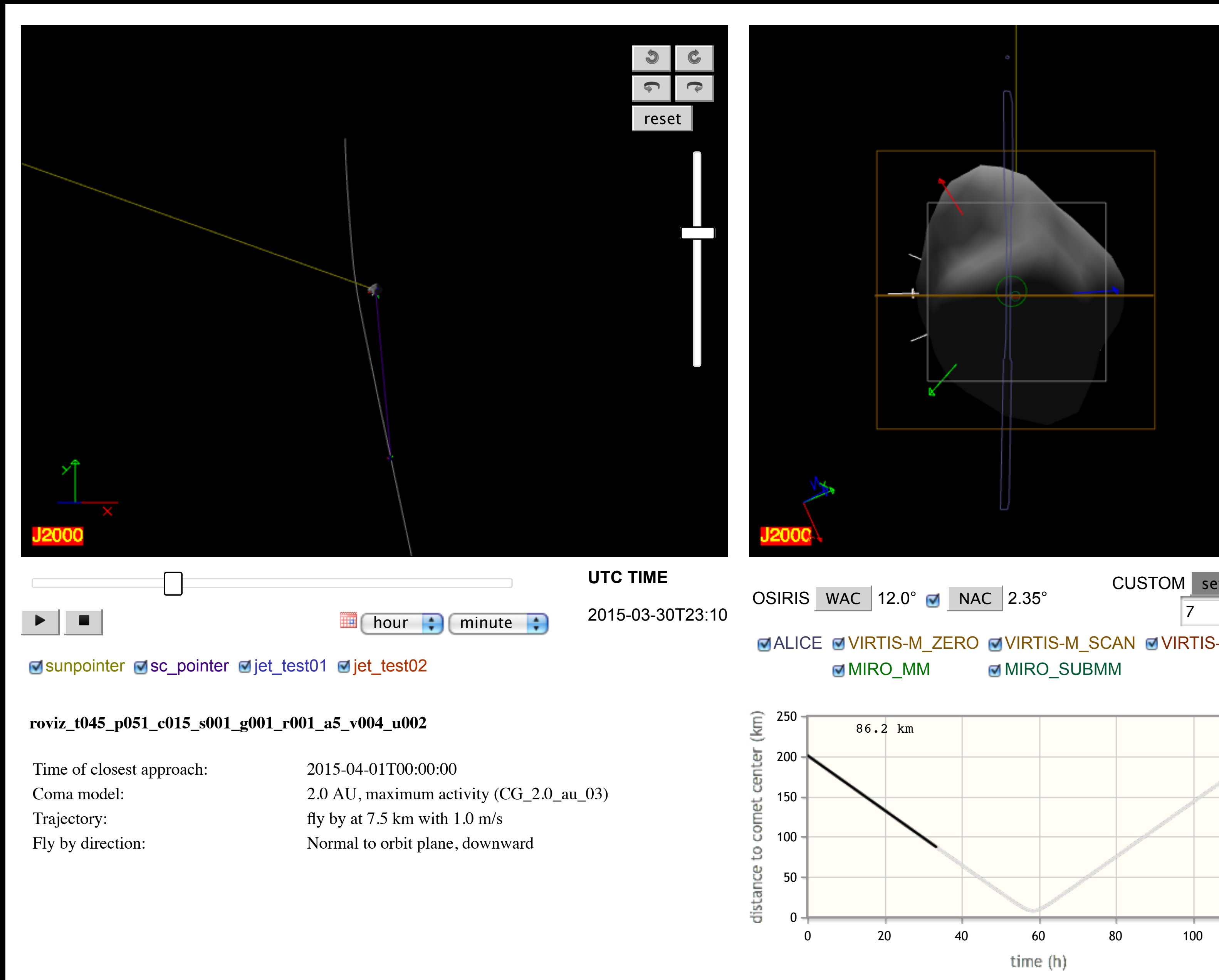
- Team at European Space Astronomy Center (ESAC) near Madrid, Spain
  - Developing the SGS Software for science operations of the Rosetta Orbiter
  - Team (with instrument teams) responsible for science operations of Rosetta Orbiter
  - JPL/NASA, ESAC/ESA partnership to develop Rosetta SGS Scheduling Component (RSSC), automated scheduler, adapting ASPEN
  - While RSSC is a small part of RSGS, since IWPSS is a planning/scheduling workshop, this talk focuses on RSSC

Skeleton Plan Generation

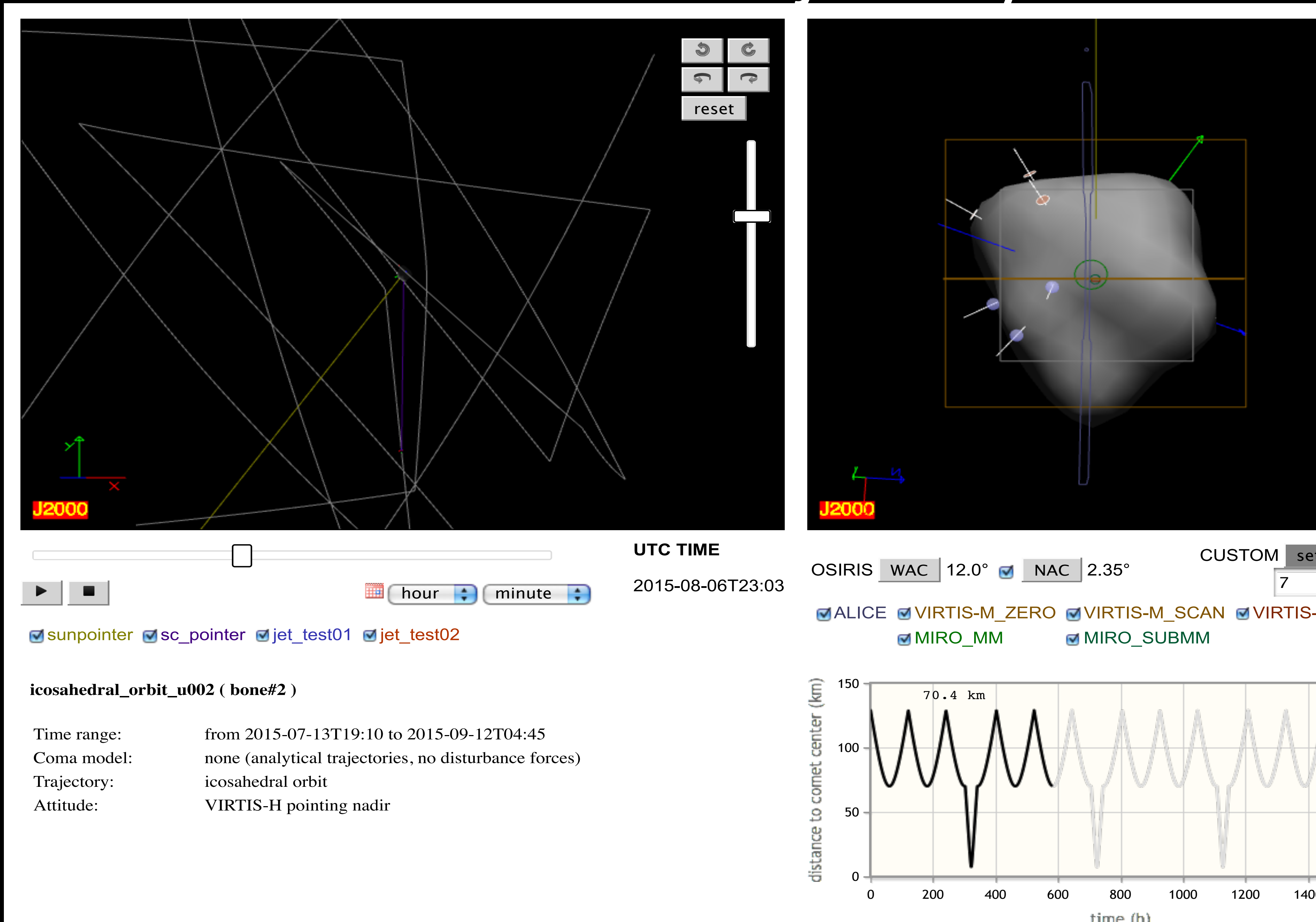
- Rosetta is unique in that the spacecraft trajectory has considerable flexibility since C-G is a low gravity environment
- Skeleton plan development is a process in which the Rosetta team considers alternate trajectories based on science return.
  - Propose a trajectory
  - Evaluate observations possible
  - Re-propose trajectory
  - …

Close Flyby Trajectory

Example – 2.0AU heliocentric distance, close flyby to 7.5km



Icosahedral trajectory



Skeleton Planning

- Ends when
  - Have a nominal skeleton plan from start to end of mission

Rosetta Science Planning

- Skeleton planning (see visualizations)
  - Before escort phase operations begins
  - Derive a set of baseline science plans
  - Presume predetermined trajectories
  - Refine Science activities for each flyby, “bone”
  - RSSC supports bone development
- Long Term Planning
  - > 8 weeks out – finalize bone selection for 4-week block, adjust bone to context (RSSC)
- Medium Term Planning
  - 4-8 weeks out, refine observations for block (RSSC)
- Short Term Planning
  - 1-4 weeks out, can make only minor tweaks to plan (RSSC) such as timing relative to closest approach, refine pointing, etc.

- At any point in time during escort operations, 2 x 4 week blocks are in LTP, 1 is in MTP, one is in STP, one is in execution.

Scheduling Constraints

- Rosetta has a range of scheduling sub-problems and constraints

Scheduling Rules

- Repeat while repetition [temporal constraint]
  - Schedule up to N while respecting constraints
- Repeat/insert while observation/window
  - Schedule during other observations/condition
- Start/end when start/end
  - Temporal relationship to a different obs type
- Expansion
  - Can iterate over finite sets of targets
  - Can require cross product of conditions
    - Solar zenith angle, distance to target, …

Science Campaign Definition

Alice great circle scan around S/C X axis

Objective: Distribution of coma dust, atoms, and ions

Scheduling Rules:

Mission Phases: From begin of 2015 to end of mission

Repetition: Weekly.

Observation Definition:

Conditions: When in flyby trajectories, observation should be performed at distances > 100 km. Preferred when spacecraft is within 3 degrees of terminator.

Pointing Profile: Spacecraft X-axis pointing to the sun. 360° rotation around x-axis. Will scan through the nucleus if the spacecraft is close to the terminator.

Activity Profile (Mode): Perpetual pixel list

Duration: 10 hours (Corresponds to a slew velocity of 36°/hour or 0.01°/s). May depend on activity. TBC.

Data Volume [MB]: 35-140 per observation, depending on count rate [TBC]. Duration may be defined to keep expected data volume (total number of photons) constant.

Power [W]: 4

In-Situ vs. Remote Sensing

DUST INSTRUMENTS status (2/2)

Cosima fluence 10 mu (diameter) for 2 AU

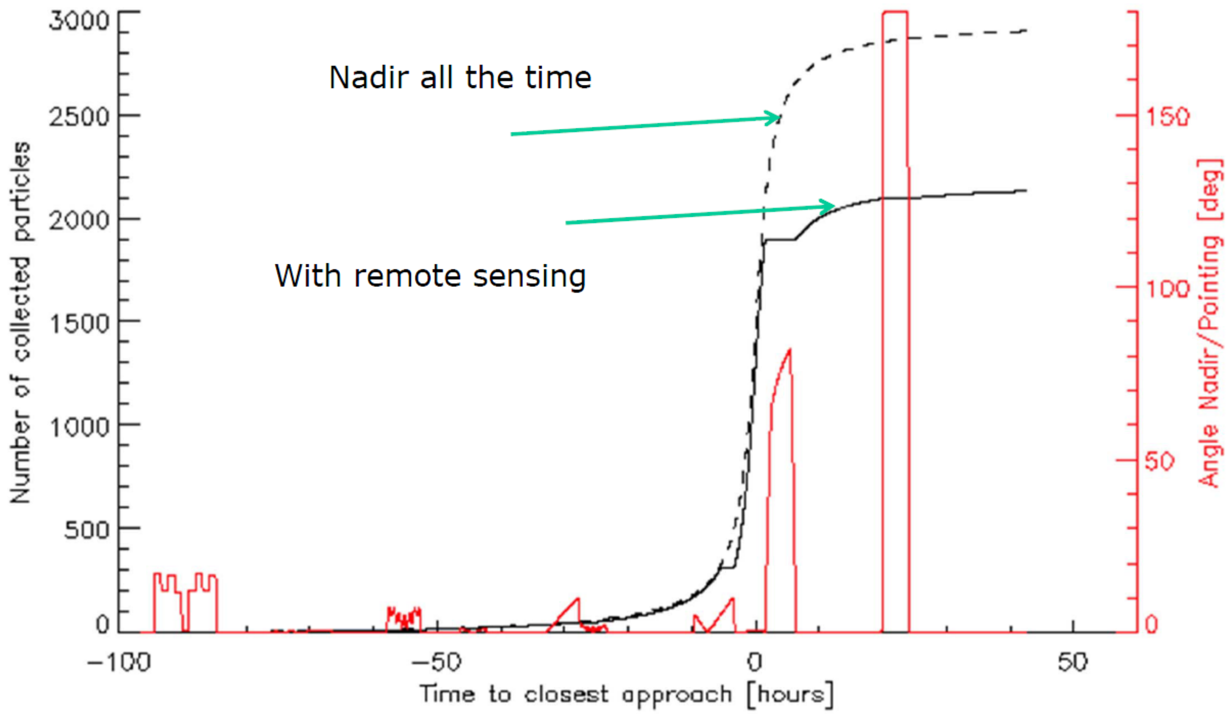


Figure of merit for in-situ campaigns, for each maneuver which affects FOM, consider impact before accepting maneuver.

Observation Definition

- Instrument/Modes/Duration
- Geometric constraints
  - Requirements on parameters defined by trajectory
  - Attitude requirements
- Dynamic: are expected to change during mission
- ASPEN model generated on the fly from definitions each invocation.

Sequence Constraints

- Instrument sequences obey certain operations constraints
  - Acceptable state transitions
  - Transitions by "actions/commands"
  - Rules on startup, shutdown
    - May not shut down if consecutive observations
- ASPEN creates instrument models on startup by parsing input XML file

Windows of Opportunity

- Geometric, non-pointing, constraints
- Trajectory dependent, pointing independent
- Compiled before ASPEN invoked, converted to time windows
  - E.g. distance to nucleus > 74km
  - 5 < emission angle < 35

Spacecraft State and Resources

- Compiled into ASPEN model on startup
- Input XML (same as used by ESAC s/c sim)
- Resource usage typically determined by mode
  - Power, housekeeping data volume, science data volume,…

General constraint classes

- Typical spacecraft
  - Power, data volume, data rate
- Geometric non spacecraft pointing (WoO)
  - Trajectory dependent
  - Distance to sun, nucleus, visibility, solar zenith angle, observation angle
- Geometric spacecraft pointing
  - Align the Alice instrument slit with comet jet
  - Point Miro at the limb
  - …
- Temporal
  - Want Alice great circle every week

Pointing and Slewing

- Prime observation defines the attitude
  - Attitude may be a profile, e.g. mosaic
  - Attitude may depend on time, e.g. slew angles are smaller at distances farther from the comet
- Rider observations use the attitude of the prime
  - any number of riders on one prime
- Slew required between incompatible attitudes
- ASPEN uses "conceptual" attitudes
  - Query for prime/rider compatibility windows
  - Query for slew feasibility/duration
  - Rosetta slew times can be significant (90 minutes)
  - Future heuristics will need to be "attitude aware"

Engineering Activities

- Reaction Wheel off loading (WOL)
- Navigation imaging
- Trajectory Correction Maneuvers (TCM)

- Above interfere with or interrupt many science activities.

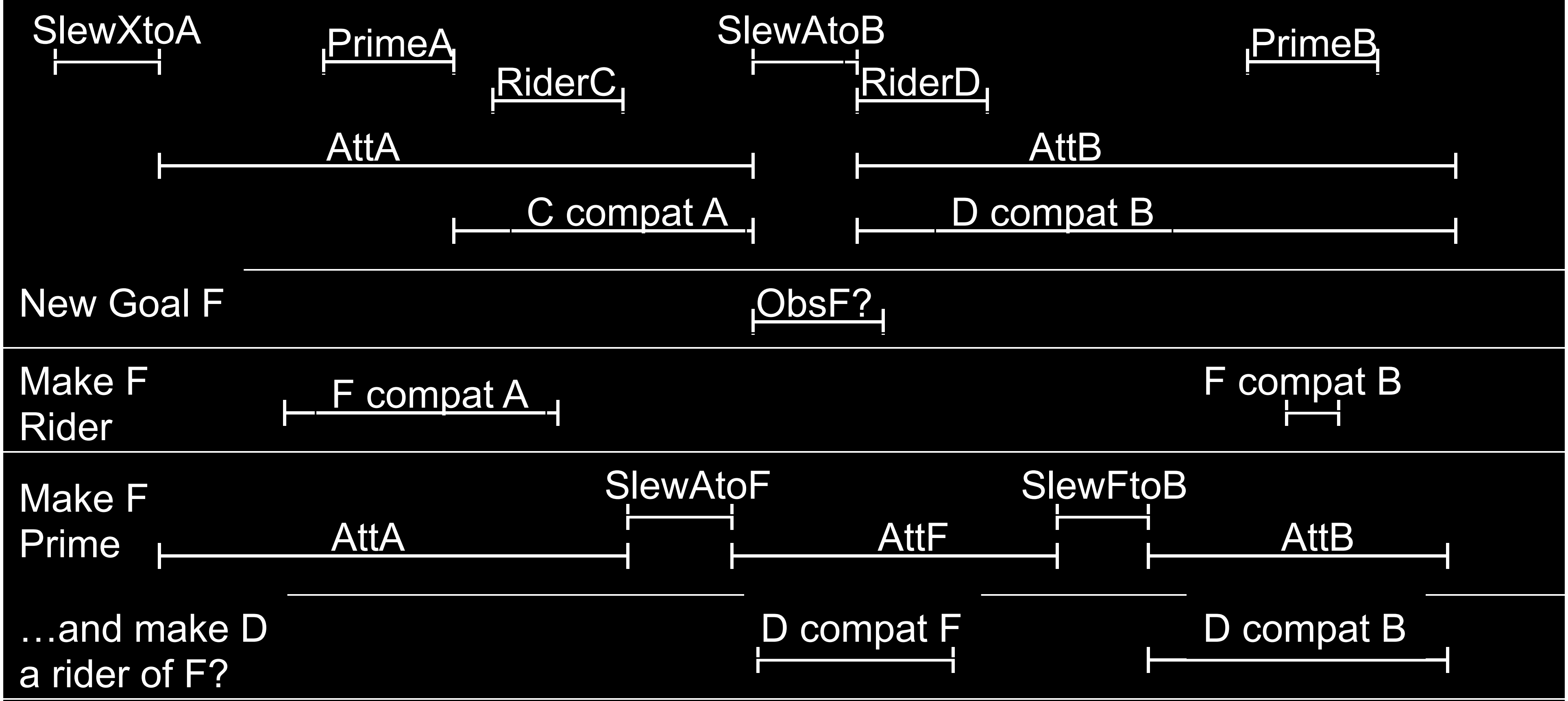
Onboard Storage, Data Management, Downlink

- All science data acquired must be downlinked
- Limited onboard storage
  - Allocated by instrument
- Rosetta receives ground station coverage at a pre-specified data rate
- Scheduling order and duration of each buffer per downlink (only 1 visit per downlink).

Current Skeleton Planning

- Constructive priority first scheduling, e.g. schedule each campaign in priority first order
- Currently prior decisions are not revisited
  - Large # of choice points
  - Easy match for Squeaky Wheel or other iterative optimization techniques

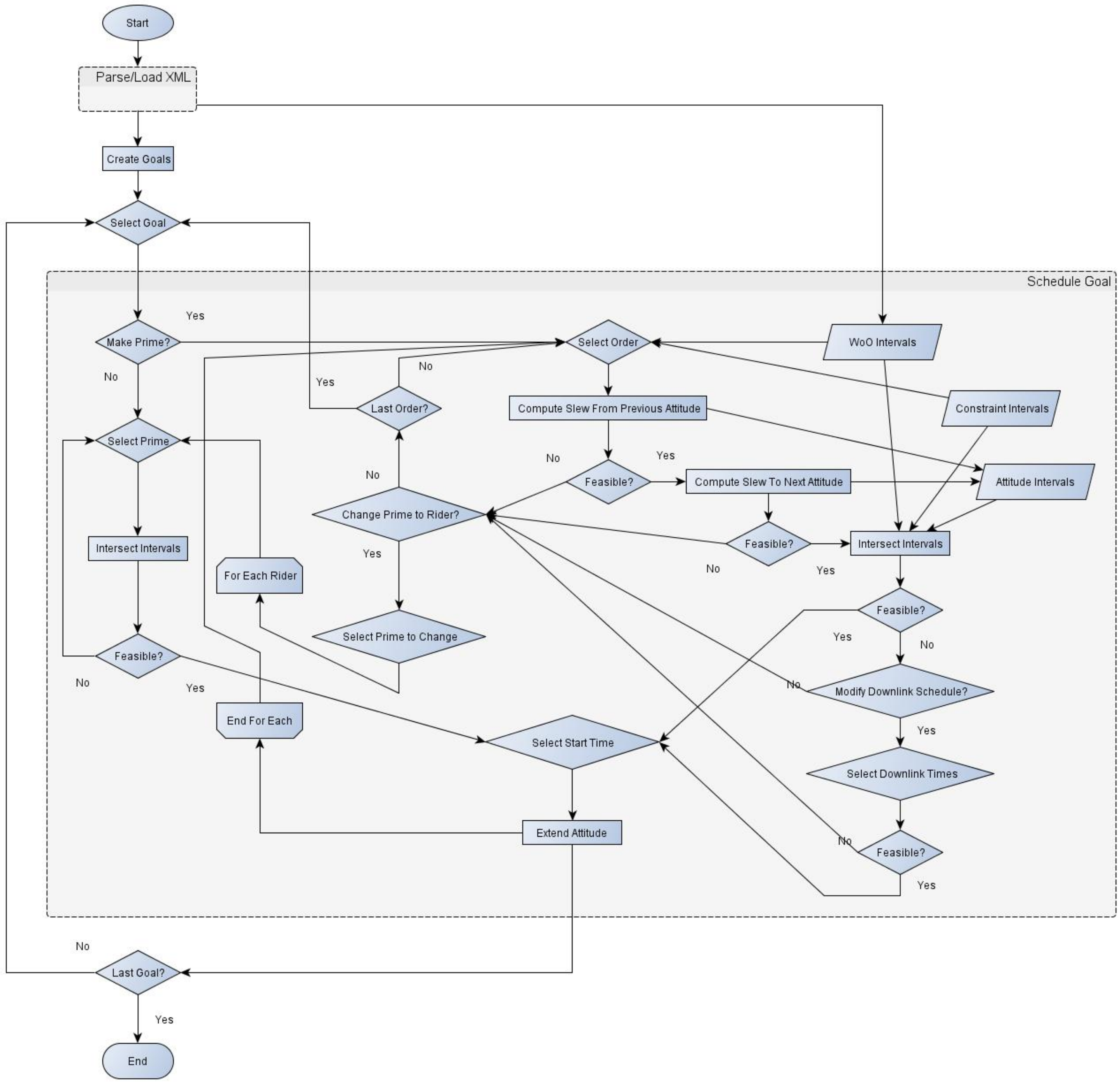
Example



Or, change A to rider and make A and C riders of F…

Also: resource/state intervals, temporal constraint intervals, WoO intervals

Choice Points



Example

- 8 week icosahedral trajectory
- ~ 50 campaigns
- ~ 300+ scheduled observations

Icosahedral

ID	ITERATION	PRIORITY	OBS	SATISFIED	NAME	RULES	DURATION
100	139	100	4	YES	ALICE Inner coma observations for Noble gas detection and mapping	REPEAT 3 [1-4] OBSERVATION 100 WHILE REPETITION SEPARATED [14d-42d]	3h
101	160	150	1	YES	ALICE Great circle scan around S/C X axis	REPEAT 5 [1-10] OBSERVATION 101 WHILE REPETITION SEPARATED [6d-8d]	10h
102	162	150	3	YES	ALICE Scan around S/C Y axis	REPEAT 3 [1-5] OBSERVATION 102 WHILE REPETITION SEPARATED [12d-16d]	5h
103	158	150	2	YES	ALICE Grain composition investigation	REPEAT 5 [1-10] OBSERVATION 103 WHILE REPETITION SEPARATED [6d-8d]	4h
104	155	150	0	NO	ALICE Detection and mapping of CO source regions	REPEAT 6 [1-12] OBSERVATION 104 WHILE REPETITION SEPARATED [23h-1d]	12h
105	148	100	0	NO	ALICE Mapping of CO in the inner coma	REPEAT 15 [1-30] OBSERVATION 105 WHILE REPETITION SEPARATED [1d-3d]	4h
106	144	100	0	NO	ALICE Search for CO extended source	REPEAT 15 [1-30] OBSERVATION 106 WHILE REPETITION SEPARATED [1d-3d]	3h
107	149	100	0	NO	ALICE Search for atomic species	REPEAT 15 [1-30] OBSERVATION 107 WHILE REPETITION SEPARATED [1d-1d12h]	1h30m
108	140	100	0	NO	ALICE Investigation of ice rich/active regions	REPEAT 2 [1-2] OBSERVATION 108 WHILE REPETITION SEPARATED [7d-21d]	3h
109	135	100	0	NO	ALICE Surface mapping	REPEAT 2 [1-3] OBSERVATION 109 WHILE REPETITION SEPARATED [14d-21d]	10h
110	126	100	3	YES	ALICE Ion tail observations	REPEAT 2 [1-3] OBSERVATION 110 WHILE REPETITION SEPARATED [14d-21d]	6h
111	141	100	3	YES	ALICE Search for sunward ion emission	REPEAT 2 [1-3] OBSERVATION 111 WHILE REPETITION SEPARATED [14d-21d]	3h
112	146	100	3	YES	ALICE Calibrations	REPEAT 2 [1-3] OBSERVATION 112 WHILE REPETITION SEPARATED [12d-16d]	1h
200	129	100	2	YES	MIRO Global coma scan for gas distribution	REPEAT 2 [1-3] OBSERVATION 200 WHILE REPETITION SEPARATED [20d-40d]	20h
201	145	100	0	NO	MIRO Limb to limb scan for gas distribution	REPEAT 6 [1-12] OBSERVATION 201 WHILE REPETITION SEPARATED [16h-1d8h]	30m
202	147	100	2	YES	MIRO Raster scan for nucleus thermal properties and inner coma gas distribution	REPEAT 2 [1-3] OBSERVATION 202 WHILE REPETITION SEPARATED [20d-40d]	12h
203	151	100	2	YES	MIRO Nucleus cross scan	REPEAT 2 [1-3] OBSERVATION 203 WHILE REPETITION SEPARATED [20d-40d]	12h
204	127	100	11	YES	MIRO Imaging of targeted locations on nucleus	REPEAT 6 [1-11] OBSERVATION 204 WHILE REPETITION SEPARATED [4d-10d]	4h
205	125	100	11	YES	MIRO Imaging of targeted locations/features in the coma	REPEAT 6 [1-11] OBSERVATION 205 WHILE REPETITION SEPARATED [4d-10d]	4h
206	153	150	2	YES	MIRO Inside-out coma observation	REPEAT 2 [1-3] OBSERVATION 206 WHILE REPETITION SEPARATED [16d-17d]	1h
207	159	150	2	YES	MIRO High resolution imaging of random nucleus locations	REPEAT 2 [1-3] OBSERVATION 207 WHILE REPETITION SEPARATED [16d-17d]	1h
208	157	150	0	NO	MIRO Polarisation maps of nucleus	REPEAT 2 [1-3] OBSERVATION 208 WHILE REPETITION SEPARATED [14d-16d]	12h
209	161	150	3	YES	MIRO Limb sounding along spacecraft trajectory	REPEAT 2 [1-3] OBSERVATION 209 WHILE REPETITION SEPARATED [14d-16d]	30m-1h
210	156	150	3	YES	MIRO Nucleus properties during polar night	REPEAT 2 [1-3] OBSERVATION 210 WHILE REPETITION SEPARATED [14d-16d]	1h

RSSC Status

- SGS software integrated in series of spirals
  - June 2012 TS0
  - Nov 2012 TS1
  - March 2013 TS2
  - June 2013 TS3
  - July 2013 end to end integration w. ESOC
  - End 2013 system operational

We are here

Related Work

- Most similar work is observatory scheduling
- SPIKE - suitability intervals, parameter preferences
- MUSE – multi-objective optimization

Conclusions

- Rosetta is quite complex with 4 remote sensing instruments and 11 total instruments
- Competing science campaigns
- Off nadir remote science competes with in-situ
- Most constraints are soft