

Scheduling Science Campaigns for the Rosetta Mission: A Preliminary Report

Steve Chien, Gregg Rabideau, Daniel Tran

Jet Propulsion Laboratory, California Institute of Technology

Federico Nespoli, David Frew, Harold Metselaar, Manuel Fernandez ,

Michael Kueppers, Laurence O'Rourke

European Space Astronomy Center, European Space Agency

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

Rosetta Science Ground Segment (SGS)

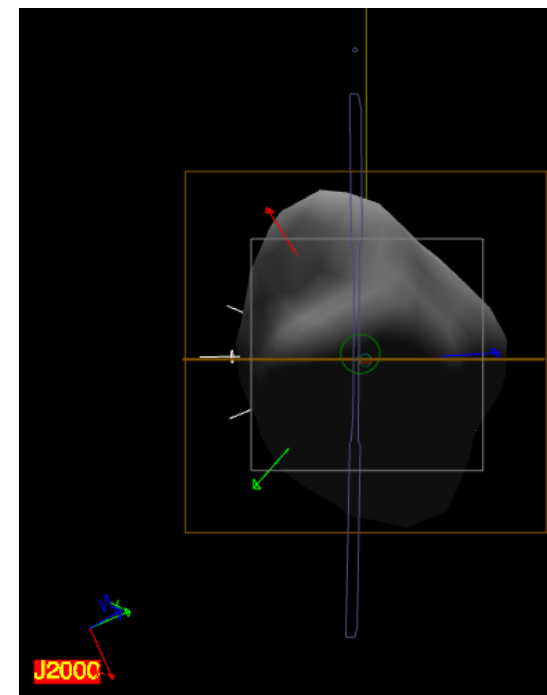
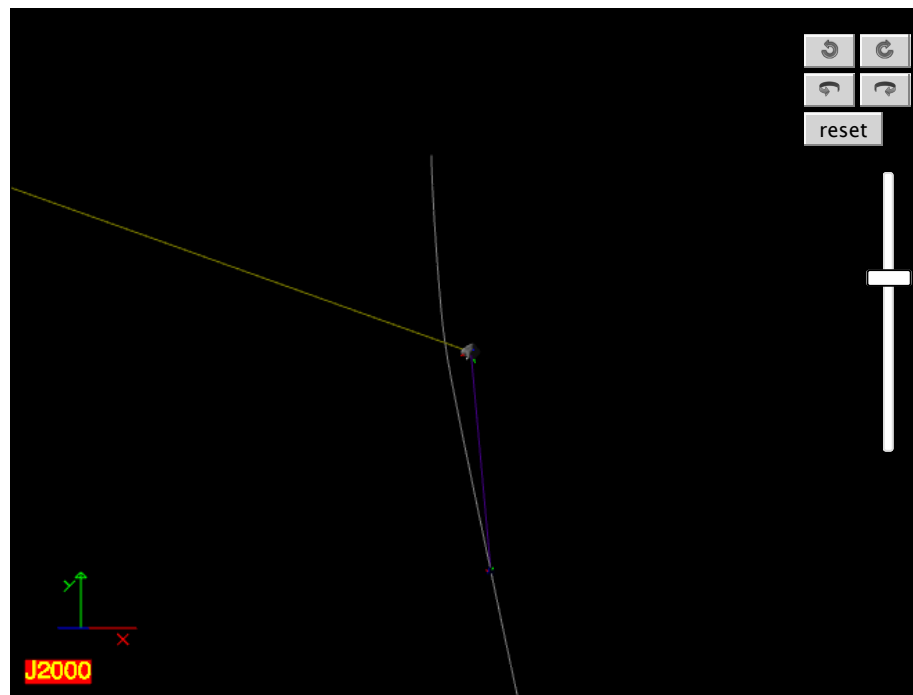
- Team at European Space Astronomy Center (ESAC) near Madrid, Spain
 - Developing the SGS Software for science operations of the Rosetta Orbiter
 - Team (with instrument teams) responsible for science operations of Rosetta Orbiter
 - JPL/NASA, ESAC/ESA partnership to develop Rosetta SGS Scheduling Component (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



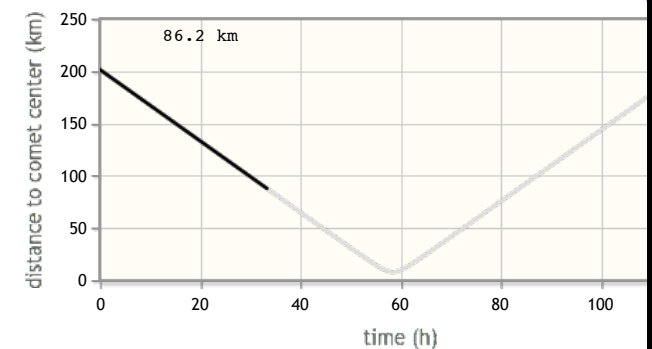
☒ sunpointer ☒ sc_pointer ☒ jet_test01 ☒ jet_test02

roviz_t045_p051_c015_s001_g001_r001_a5_v004_u002

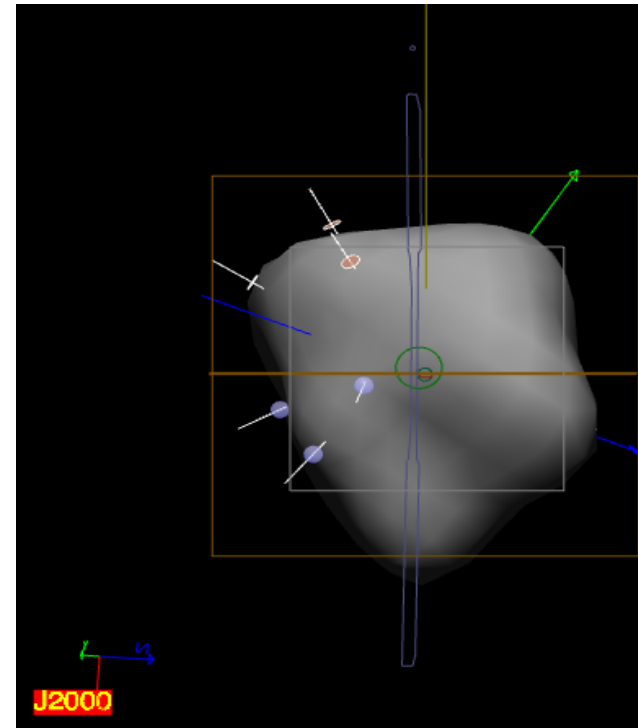
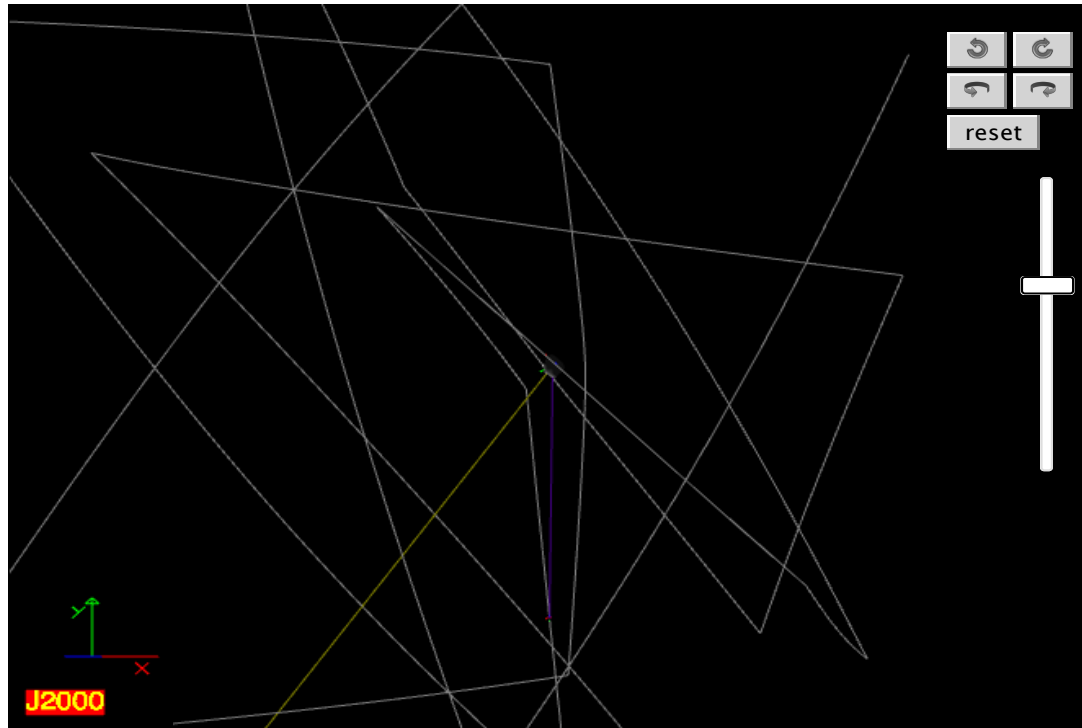
Time of closest approach: 2015-04-01T00:00:00
Coma model: 2.0 AU, maximum activity (CG_2.0_au_03)
Trajectory: fly by at 7.5 km with 1.0 m/s
Fly by direction: Normal to orbit plane, downward

UTC TIME
2015-03-30T23:10

OSIRIS WAC 12.0° ☒ NAC 2.35° ☒ CUSTOM set 7
☒ ALICE ☒ VIRTIS-M_ZERO ☒ VIRTIS-M_SCAN ☒ VIRTIS-H
☒ MIRO_MM ☒ MIRO_SUBMM



Icosahedral trajectory

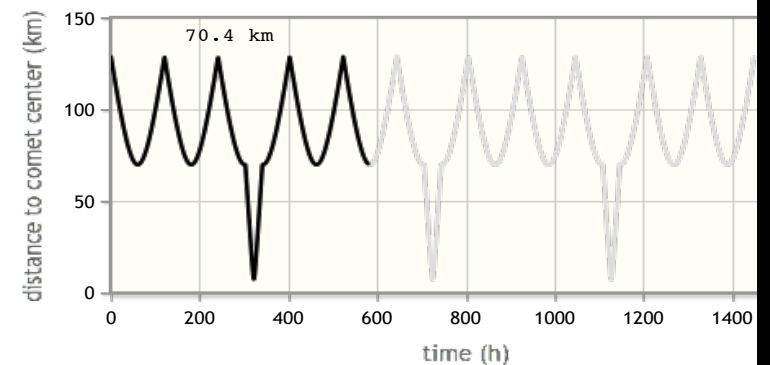


icosahedral_orbit_u002 (bone#2)

Time range: from 2015-07-13T19:10 to 2015-09-12T04:45
Coma model: none (analytical trajectories, no disturbance forces)
Trajectory: icosahedral orbit
Attitude: VIRTIS-H pointing nadir

OSIRIS WAC 12.0° ☒ NAC 2.35° ☒ CUSTOM set 7

☒ ALICE ☒ VIRTIS-M_ZERO ☒ VIRTIS-M_SCAN ☒ VIRTIS-H
☒ MIRO_MM ☒ MIRO_SUBMM



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 $36^\circ/\text{hour}$ or $0.01^\circ/\text{s}$). 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 μ (diameter) for 2 AU

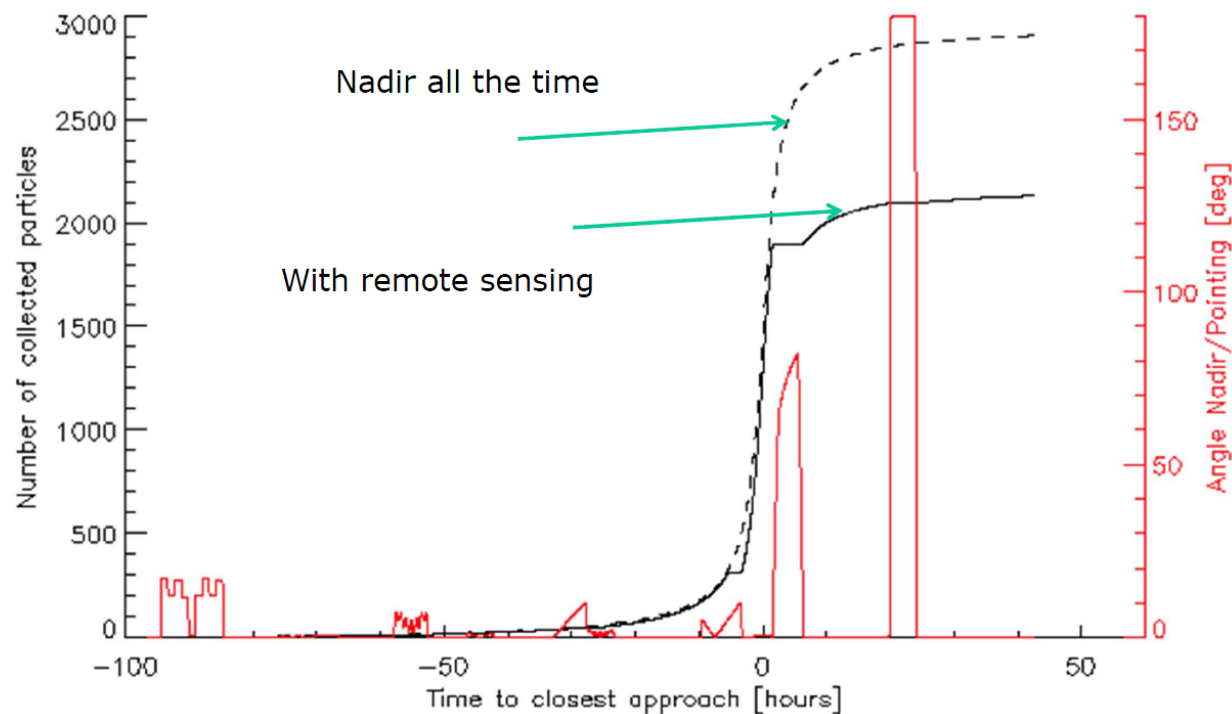


Figure of merit for in-situ campaigns, for each maneuver which affects FOM, consider impact before accepting maneuver.

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 $> 74\text{km}$
 - $5 < \text{emission angle} < 35$

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



New Goal F ObsF?

Make F Rider F compat A F compat B

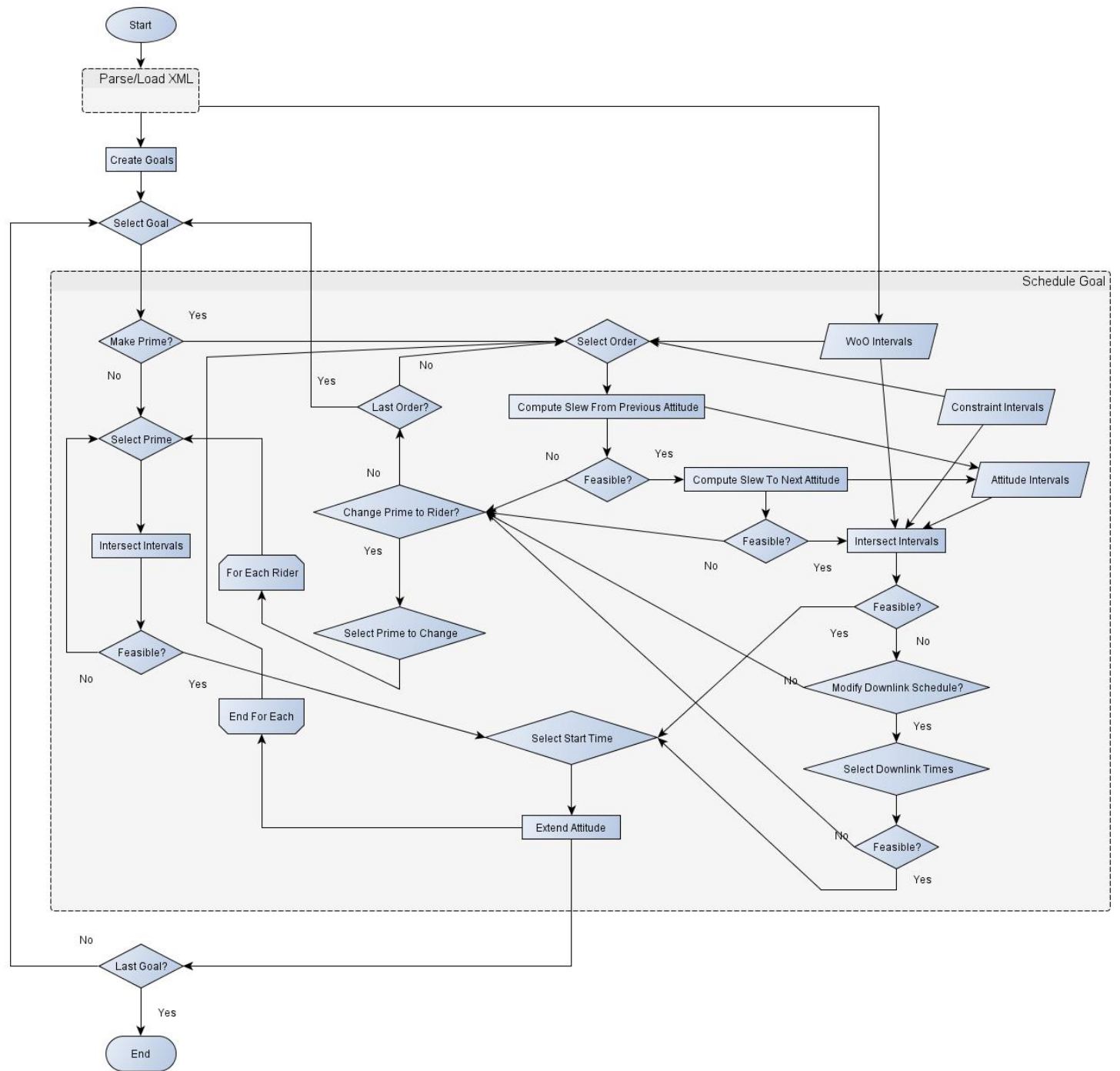
Make F Prime AttA SlewAtoF AttF SlewFtoB AttB

...and make D a rider of F? D compat F D compat B

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

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

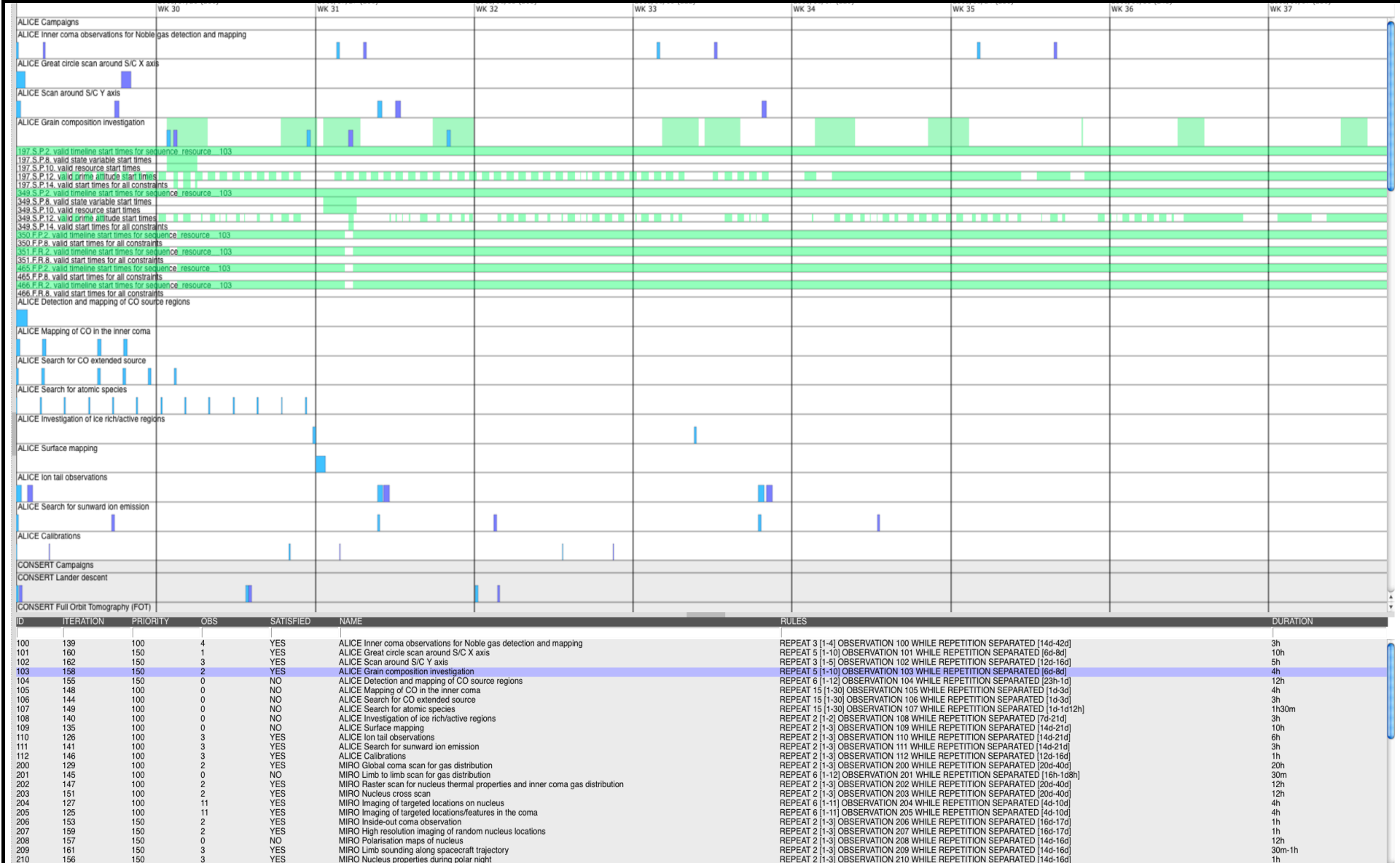
Choice Points



Example

- 8 week icosahedral trajectory
- ~ 50 campaigns
- ~ 300+ scheduled observations
- ~40,000 planned activities

Icosahedral



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