Multi-Objective Scheduling for the Cluster II Constellation

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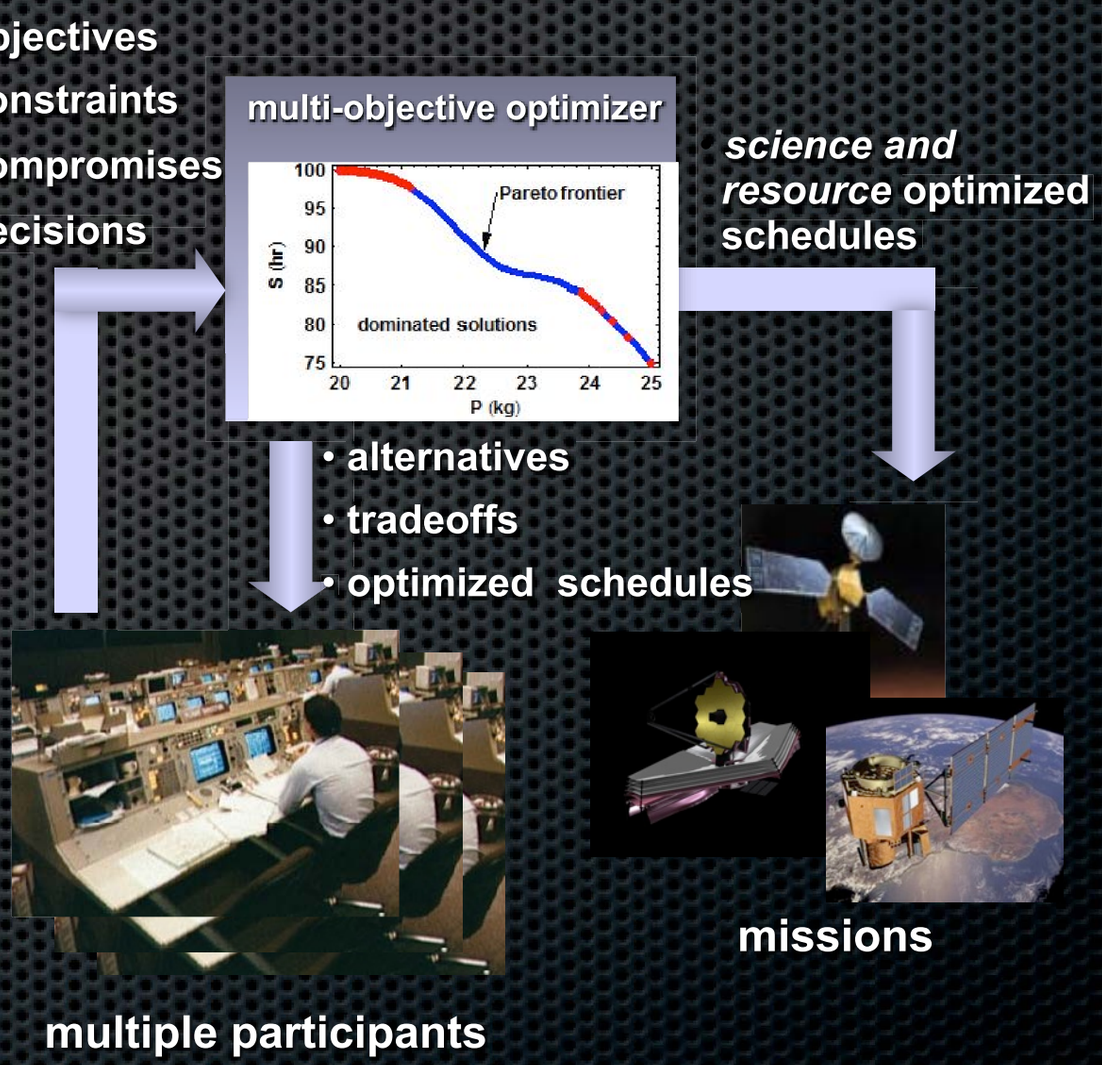
Outline

- Overview of the research program
  - Motivation
  - Approach
- System architecture
- Current applications
- Next steps and new applications



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  - Fit into a dynamic environment —
    - Changing science goals
    - Changing spacecraft capabilities
  - Optimize conflicting goals for multiple constituents
    - Science return, engineering, calibration, stability of the plan itself …
    - Hard to quantify and make explicit goals — communication problem

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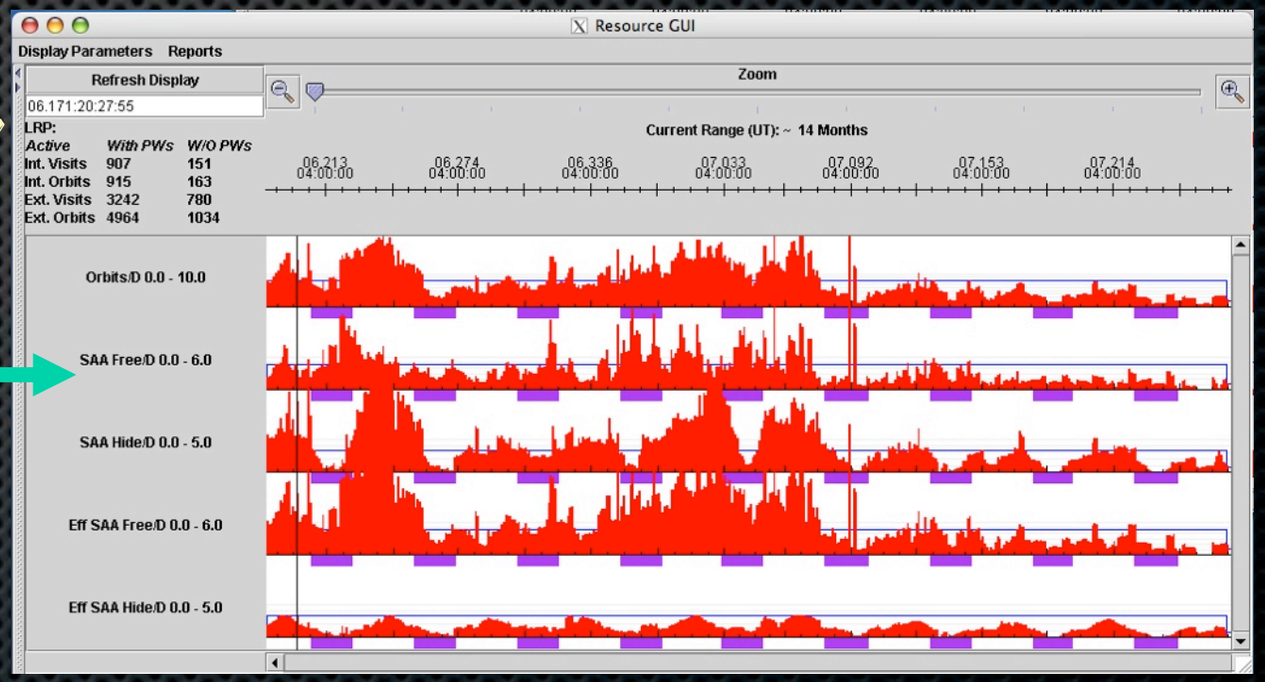

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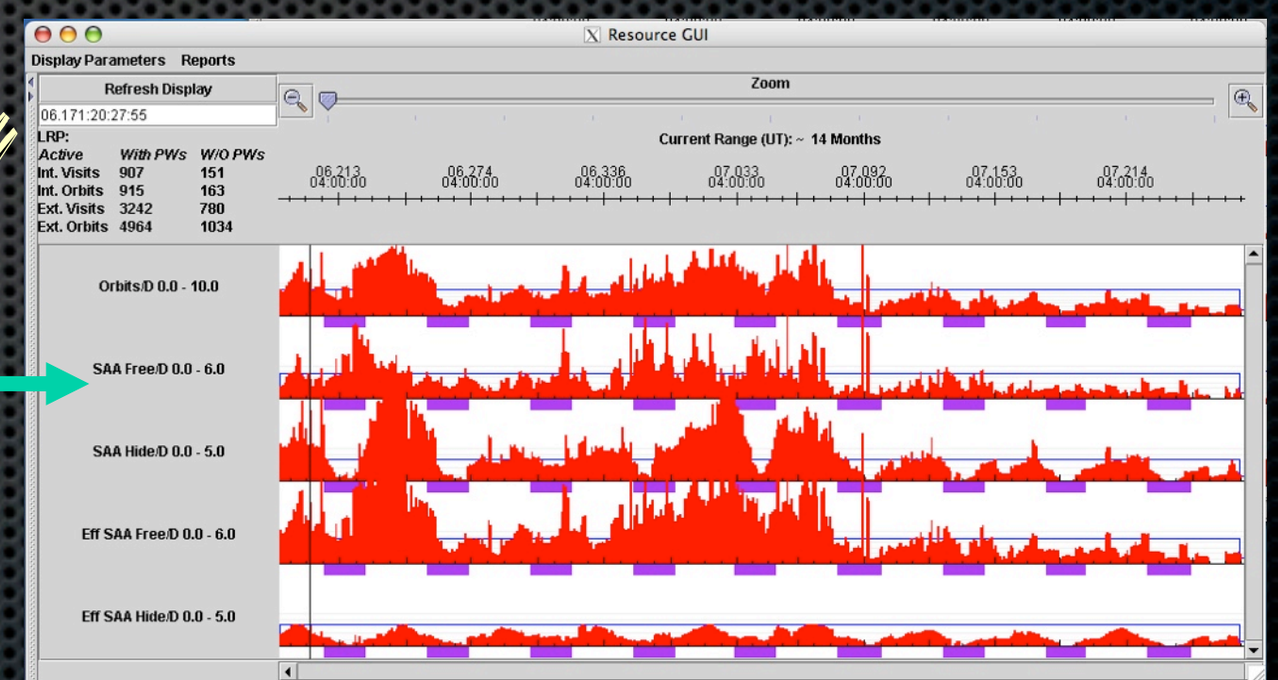
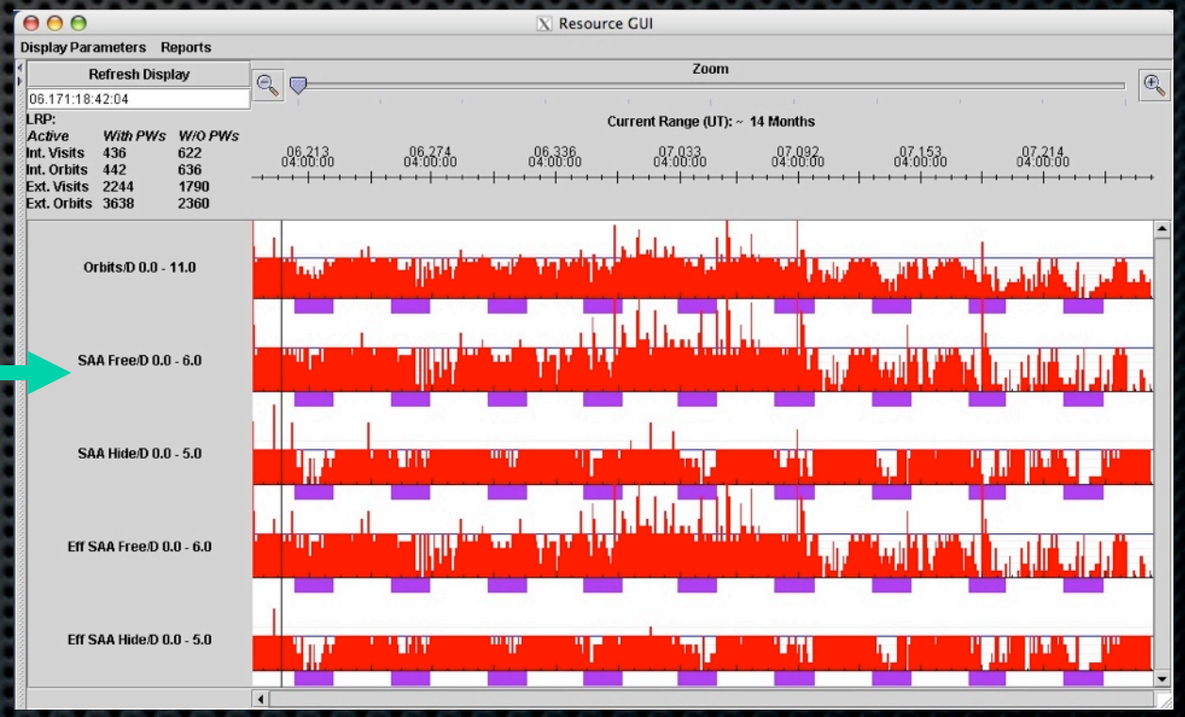
  - multiple participants



Project Objectives

- Effective decision support tools that enable participants to optimize schedules in a collaborative manner
  - enable integration with existing tools



Multi-Objective Scheduling

- Effective scheduling of space based astronomy missions requires the ability to make trade-offs among competing mission objectives:
  - Time on target, minimizing use of consumables, minimizing the use of critical mechanisms, preferring the higher priority science, ...

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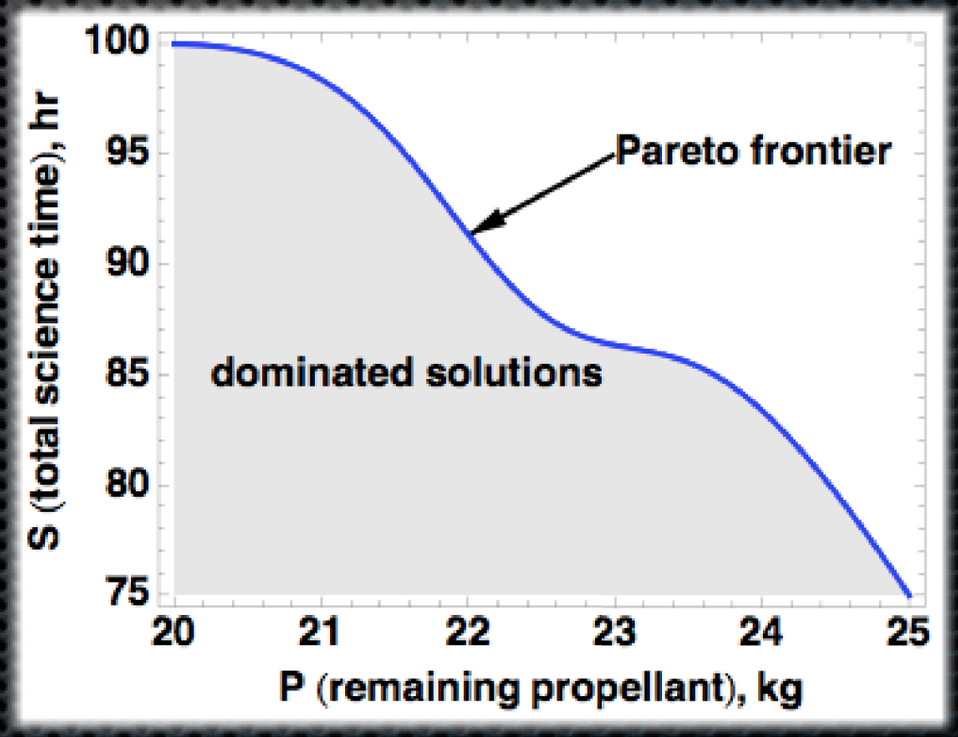

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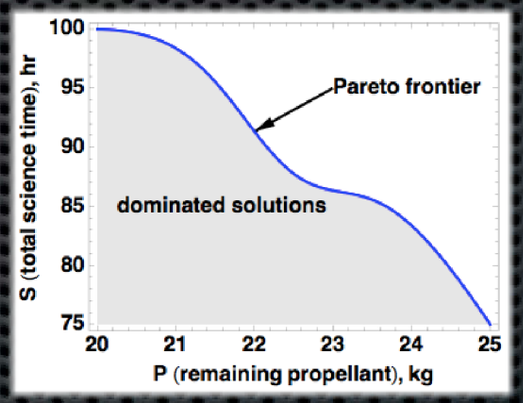

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  - e.g. mission science community versus engineering

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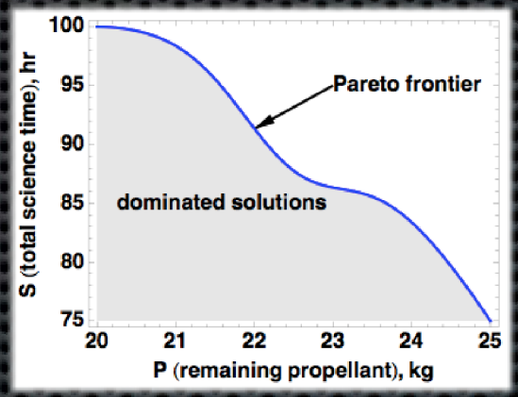


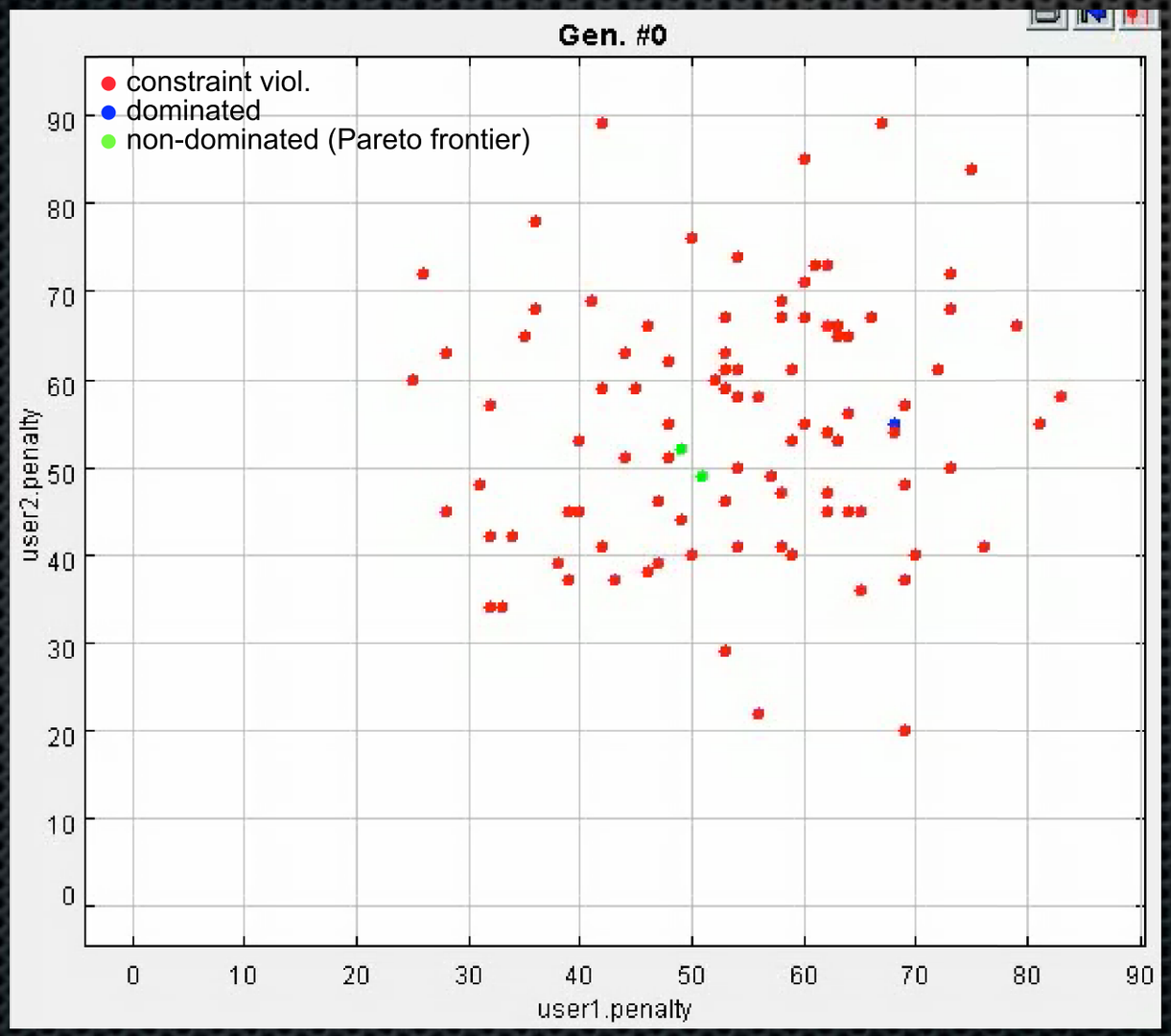
- Objectives have different constituents lobbying for them
  - e.g. mission science community versus engineering
- The traditional approach is to combine objectives, e.g. take the weighted average of separate objectives, e.g. $\sum \alpha_i f_i(x)$
  - But: combining objectives loses information and pre-determines the trade-offs among them

Multi-Objective Solution Approaches

- Multi-Objective Scheduling:
  - Explicitly maintain and exploit multiple objectives during scheduling
  - Use algorithms that build up the (approximate) Pareto optimal frontier from a population of candidate schedules
    - i.e. “non-dominated” solutions, such that no other candidate is better, considering all objectives.
    - Among the best choices are evolutionary algorithms such as GDE3 (Generalized Differential Evolution 3) ...

Converging to the Pareto Frontier Using an Evolutionary Algorithm

- Example: two objectives to minimize:

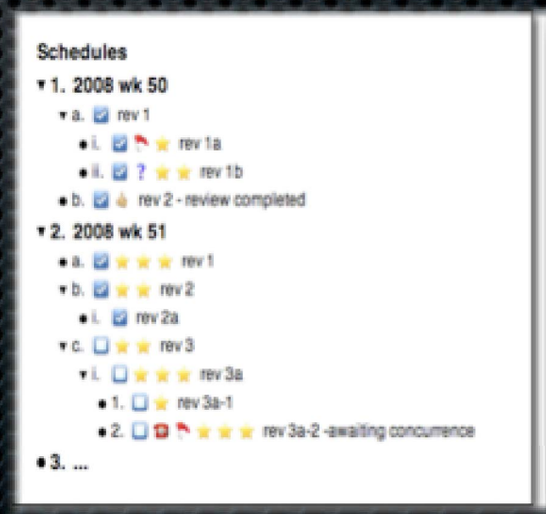


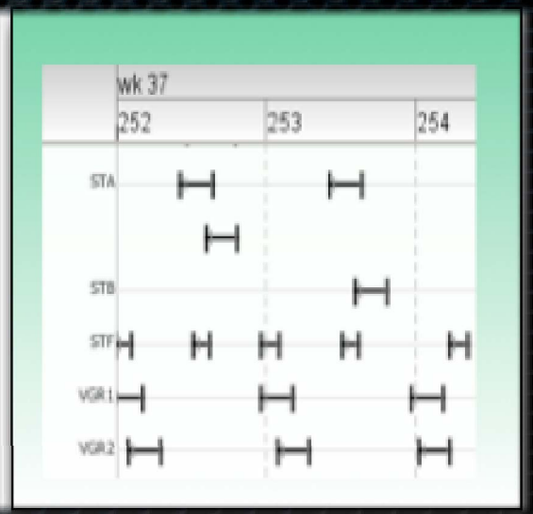
The Pareto frontier doesn't give you a single solution, but it does narrow down to a set and shows you the shape of the tradoff curve

Multi-Participant

- The Pareto frontier gives participants a powerful view into the optimal trade-off space, but they still need to agree on a particular candidate schedule
- Multi-*participant* approaches can be combined with multi-objective scheduling to provide distributed decision support
  - Mixed-initiative multi-objective planning — support the end user in making trade offs
    - Automate when possible but leave final control with the user
  - Graphical internet-based tools that support multiple participants
  - Challenges include: human factors, non-simultaneous users, domain-specific scheduling GUIs

Conceptual model: threaded news/mail reader + schedule viewer





MUSE Architecture Drivers

- Distributed, collaborative exploration of the Pareto frontier
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- Distributed, collaborative exploration of the Pareto frontier
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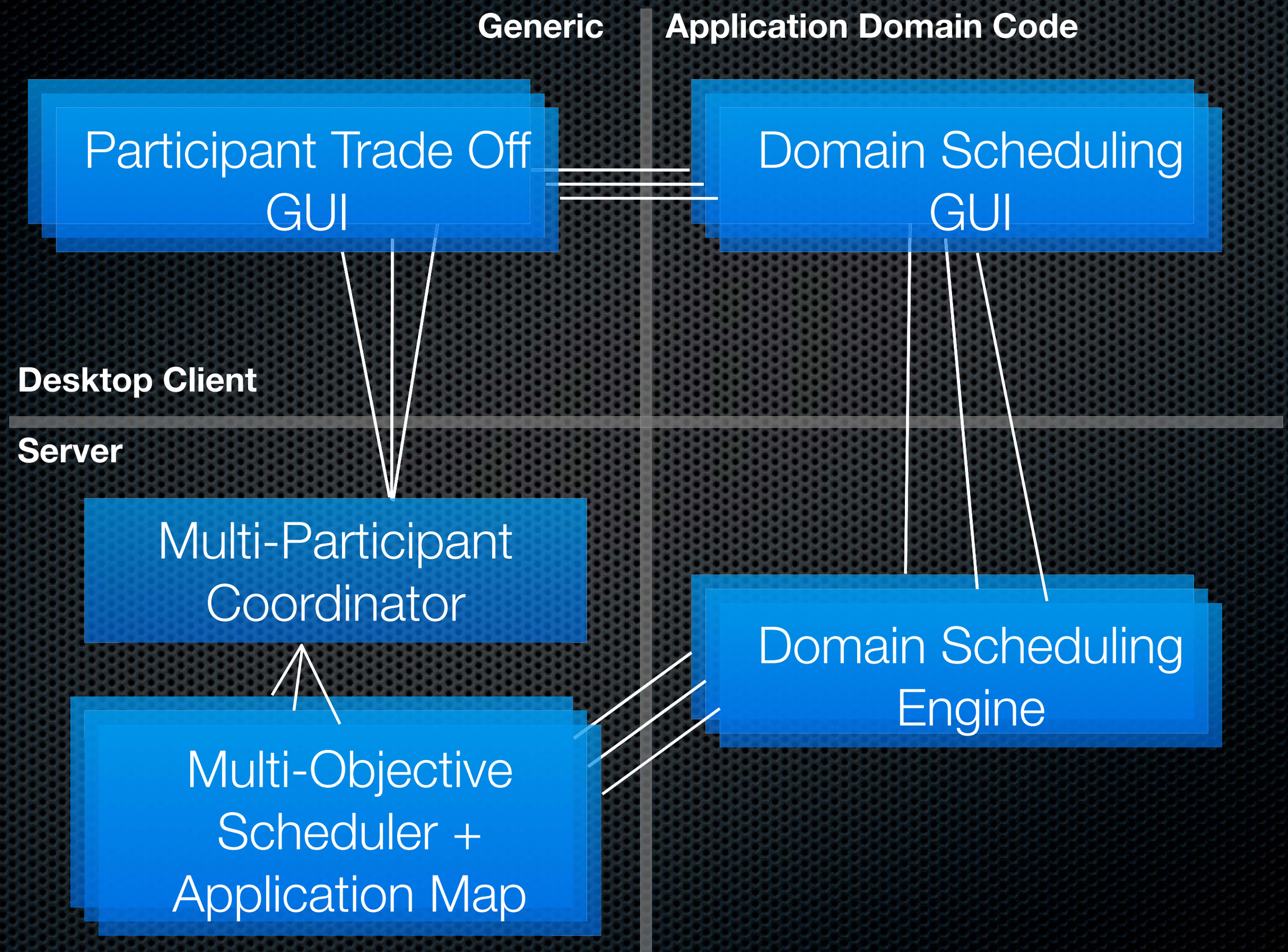
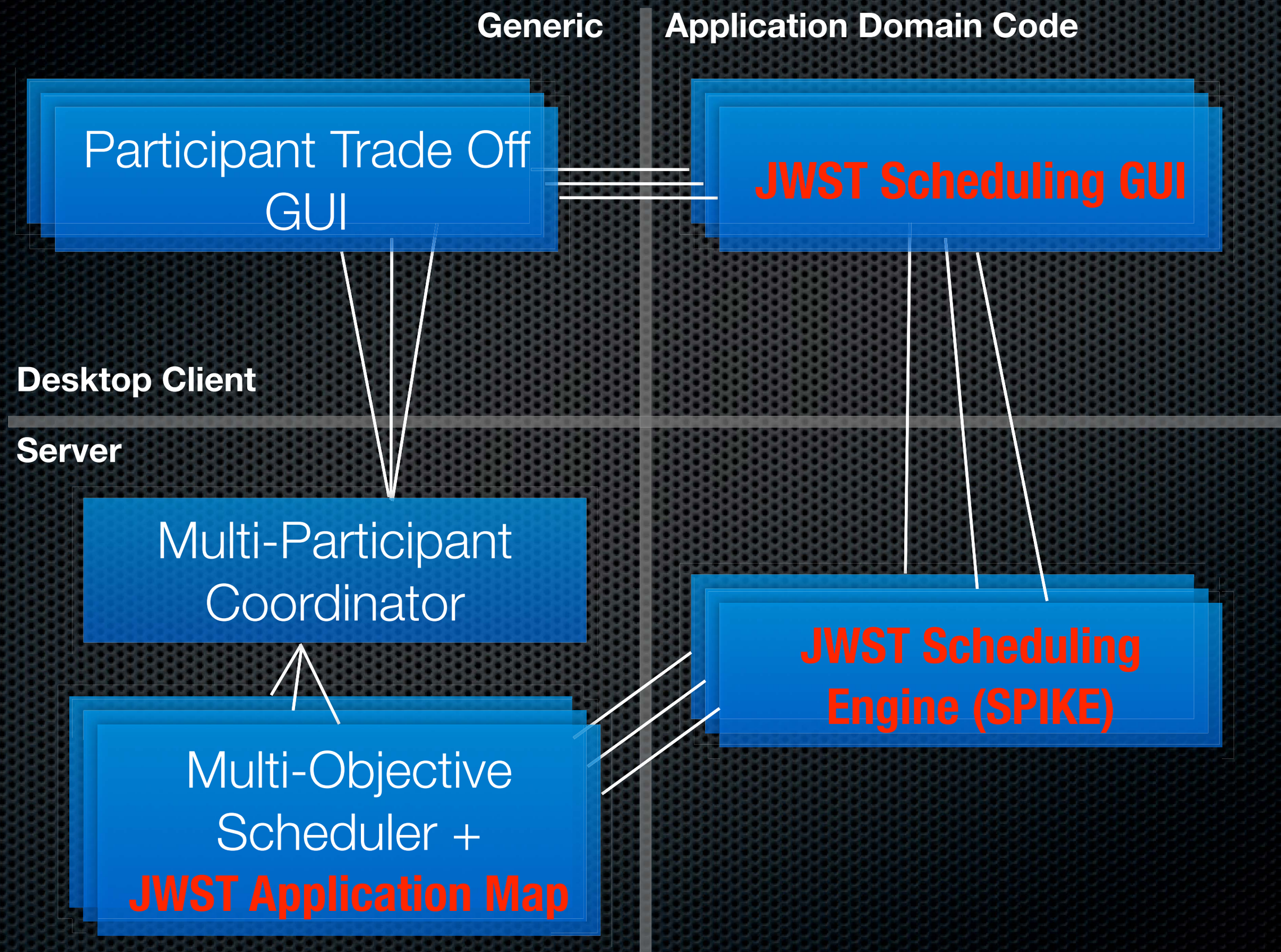
- Don’t reinvent the wheel — integrate with existing tools
- Allow for workflow and notification mechanisms

MUSE Architecture – Schematic



MUSE Architecture – JWST realization

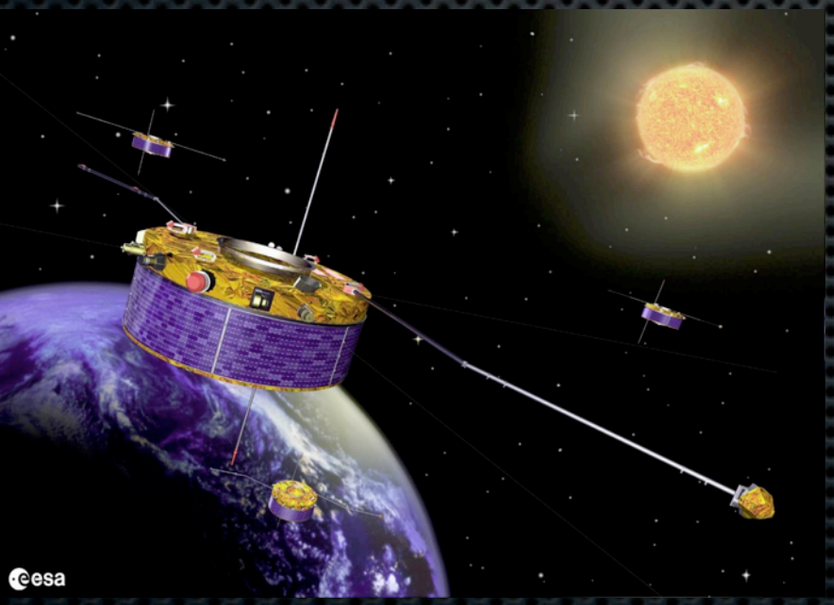


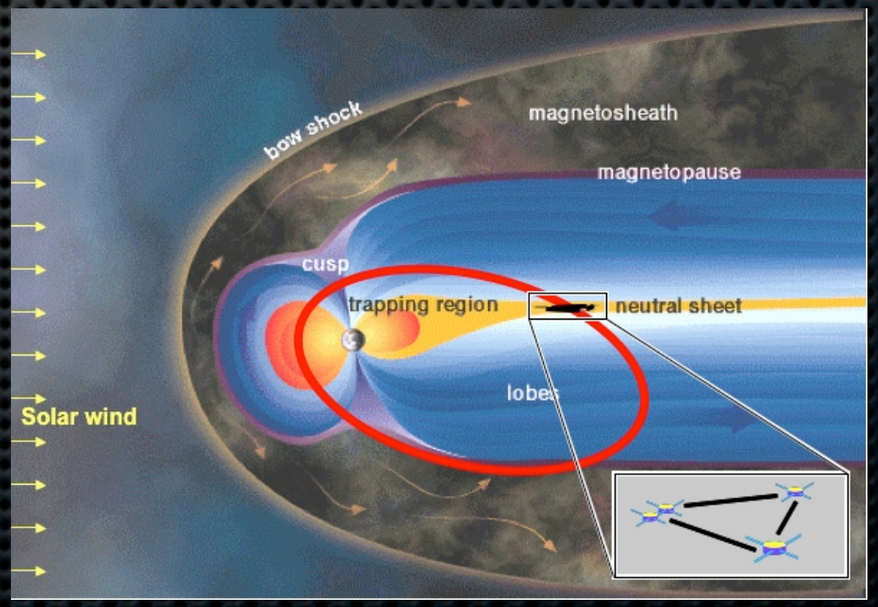
Architecture Summary

- Central scheduling engine with distributed participants and GUIs
- Applicable to multiple missions in different phases, e.g.
  - James Webb Space Telescope scheduling and long range planning
  - Cassini science planning
  - …
- Integration with existing software tools
  - different languages and architectures
- Multi-layered integration options
  - integrate with a complete implementation using our tools and expected operations concept
  - or can integrate at a higher level using your own tools

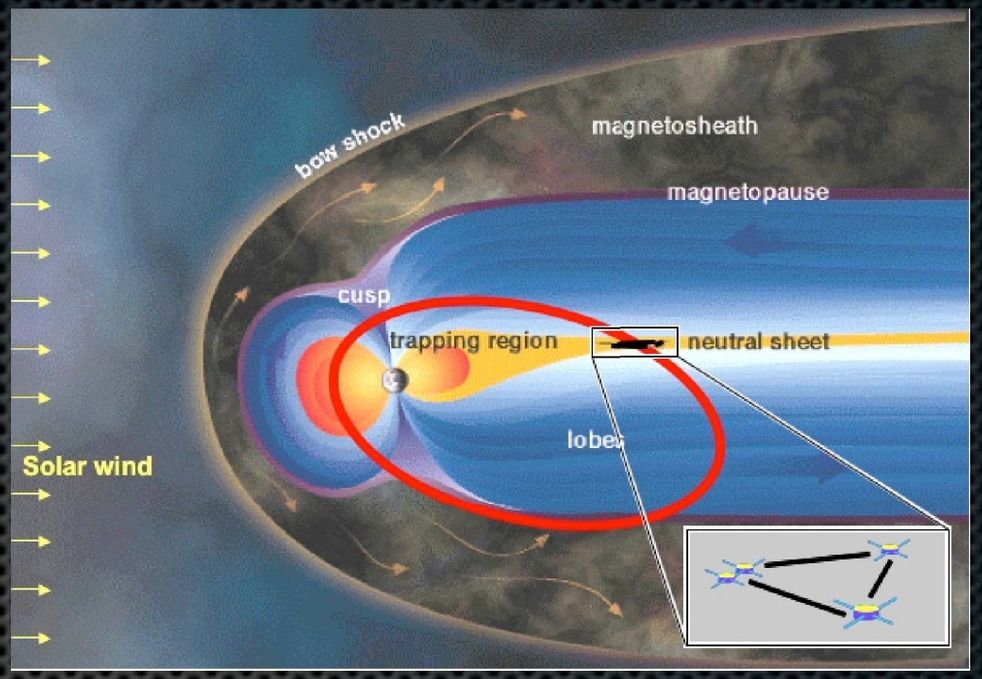
Cluster II WBD Scheduling

- Four ESA spacecraft in tetrahedral formation, investigating interaction of Earth's magnetic environment with solar wind
- WBD plasma wave experiment (Univ. Iowa) is scheduled as NASA Deep Space Network (DSN) tracking passes for a set a science opportunities (~24h/week)
- Optimization objectives include:
  - Minimize conflicts with higher priority DSN activities
  - Minimize deviation from desired distribution of priority and science category
  - Maximize passes with *preferred* s/c and multiple *simultaneous* s/c
  - Minimize clumping of selected observations





Cluster WBD Adaptation Features



- inputs:
  - opportunities list from WBD text file

Type	Start		End		Target	Mars vis	S/c	Duration	Start	End
Highest:										
WBD_TO_CAN	121	02:24	121	04:09	EQUA	Y	2	1.76	01/05/09 02:24:00	01/05/09 04:09:52
WBD_TO_PAN	121	02:51	121	04:16	EQUA	N	2	1.41	01/05/09 02:51:33	01/05/09 04:16:14
WBD_TO_PAN	121	04:16	121	05:11	EQUA	N	2	0.93	01/05/09 04:16:14	01/05/09 05:11:49
WBD_TO_PAN	121	04:20	121	05:11	CUSP	N	2	0.86	01/05/09 04:20:00	01/05/09 05:11:49
WBD_TO_MAD	121	04:48	121	05:11	EQUA	Y	2	0.38	01/05/09 04:48:59	01/05/09 05:11:49
WBD_TO_MAD	121	04:48	121	05:11	CUSP	Y	2	0.38	01/05/09 04:48:59	01/05/09 05:11:49
WBD_TO_MAD	121	06:05	121	06:54	CUSP	Y	4	0.83	01/05/09 06:05:00	01/05/09 06:54:59
WBD_TO_PAN	121	06:05	121	06:54	CUSP	N	4	0.83	01/05/09 06:05:00	01/05/09 06:54:59
WBD_TO_MAD	121	07:20	121	08:09	CUSP	Y	3	0.83	01/05/09 07:20:00	01/05/09 08:09:59
WBD_TO_PAN	121	07:20	121	08:09	CUSP	N	3	0.83	01/05/09 07:20:00	01/05/09 08:09:59
WBD_TO_CAN	123	08:15	123	08:45	ACCN	N	2	0.5	03/05/09 08:15:00	03/05/09 08:45:00
WBD_TO_GOL	123	15:09	123	15:59	CUSP	Y	4	0.85	03/05/09 15:09:00	03/05/09 15:59:59
WBD_TO_GOL	123	16:10	123	16:59	CUSP	Y	3	0.83	03/05/09 16:10:00	03/05/09 16:59:59
WBD_TO_CAN	124	18:10	124	18:42	VLBI	Y	1,2,3,4	0.53	04/05/09 18:10:00	04/05/09 18:42:00
WBD_TO_GOL	124	18:10	124	18:42	VLBI	Y	1,2,3,4	0.53	04/05/09 18:10:00	04/05/09 18:42:00
WBD_TO_GOL	125	19:50	125	20:20	HARP	Y	2	0.5	05/05/09 19:50:00	05/05/09 20:20:00
WBD_TO_GOL	125	20:25	125	22:40	EQUA	Y	2	2.26	05/05/09 20:25:00	05/05/09 22:40:42
WBD_TO_CAN	125	21:10	125	21:25	EQUA	Y	2	0.25	05/05/09 21:10:25	05/05/09 21:25:37
WBD_TO_CAN	125	21:25	125	23:29	EQUA	Y	2	2.07	05/05/09 21:25:37	05/05/09 23:29:59
WBD_TO_CAN	125	22:25	126	01:09	CUSP	Y	2	2.75	05/05/09 22:25:00	06/05/09 01:09:59
WBD_TO_GOL	125	22:25	125	22:40	CUSP	Y	2	0.26	05/05/09 22:25:00	05/05/09 22:40:42
WBD_TO_CAN	126	20:40	127	03:45	VLBI	Y	1,2,3,4	7.08	06/05/09 20:40:00	07/05/09 03:45:00
WBD_TO_PAN	128	05:15	128	05:46	EQUA	N	3	0.52	08/05/09 [illegible]	08/05/09 05:46:07

  - Mars viewperiods
  - existing schedule (optional, as raw file)

Cluster WBD Adaptation Features

- inputs:
  - available antennas from service alias definition (same for CLU1-4)

CLU1	gdscc	Type: SIMPLE Usage: UPLINK_DOWNLINK Marker: RISE/SET - DSS-14 - DSS-15 - DSS-24 - DSS-27	*Antenna*	*Equipment*	*Config Code*	*Setup*	*Teardown*	*Act Descr*	*Work Cat*	*SOE*
			DSS-14	NMC RRPA SHMT TLPA	N030	30m	15m	WBD	1A1	-
			DSS-15	NMC RRPA SHMT TLPA	N030	30m	15m	WBD	1A1	-
			DSS-24	NMC RRPA SHMT TLPA	N030	30m	15m	WBD	1A1	-
			DSS-27	NMC RRPA SHMT TLPA	N030	30m	15m	WBD	1A1	-
CLU1	cdscc	Type: SIMPLE Usage: UPLINK_DOWNLINK Marker: RISE/SET - DSS-34 - DSS-43 - DSS-45	*Antenna*	*Equipment*	*Config Code*	*Setup*	*Teardown*	*Act Descr*	*Work Cat*	*SOE*
			DSS-34	NMC RRPA SHMT TLPA	N030	30m	15m	WBD	1A1	-
			DSS-43	NMC RRPA SHMT TLPA	N030	30m	15m	WBD	1A1	-
			DSS-45	NMC RRPA SHMT TLPA	N030	30m	15m	WBD	1A1	-
CLU1	mdscc	Type: SIMPLE Usage: UPLINK_DOWNLINK Marker: RISE/SET - DSS-54 - DSS-63 - DSS-65	*Antenna*	*Equipment*	*Config Code*	*Setup*	*Teardown*	*Act Descr*	*Work Cat*	*SOE*
			DSS-54	NMC RRPA SHMT TLPA	N030	30m	15m	WBD	1A1	-
			DSS-63	NMC RRPA SHMT TLPA	N030	30m	15m	WBD	1A1	-
			DSS-65	NMC RRPA SHMT TLPA	N030	30m	15m	WBD	1A1	-

  - i.e. 4 @ GDSCC, 3 each @ CDSCC, MDSCC

Cluster WBD Adaptation Features (cont).

- derivation of decision points:
  - combinatoric reduction based on science objectives
    - example: “HIGHEST priority, suggest one of each (VLBI, ACCN, HARP, EQUA)”
      → constrain to include <u>exactly</u> 0 or 1 of each
    - reduces the search space, but still huge (a typical week still has ~100 billion to choose from)
- other factors:
  - combine adjacent opportunities from file into multiple combinations (e.g. for split lines due to Mars visibility changes, S/C adding or leaving an opportunity)
  - avoid time overlaps
  - alternate NOAZ/SOAZ each week
  - limit to one week boundaries per current DSN process (input files can span multiple weeks, however)

Cluster WBD Adaptation Features (cont).

- Scheduling objectives – current set includes:
  1. collisions: maximize the collision-free time in a candidate schedule w.r.t. a loaded schedule (e.g. DSN, DSS, CAS, Mars)
  2. spacing – it's better to spread out the allocations than clump them over a few days
  3. multi-S/C time and specific S/C preferences – more time with 4, 3, 2 S/C is better, and S/C preference are CLU4, CLU1, CLU2, CLU3
  4. priority mix -- PI prefers priority proportions 40%, 30%, 20%, 10% for priority HIGHEST, HIGH, MEDIUM, LOW
  5. *Mars overlap – maximize the non-overlap time w.r.t Mars viewperiods (not needed if real schedule is available)

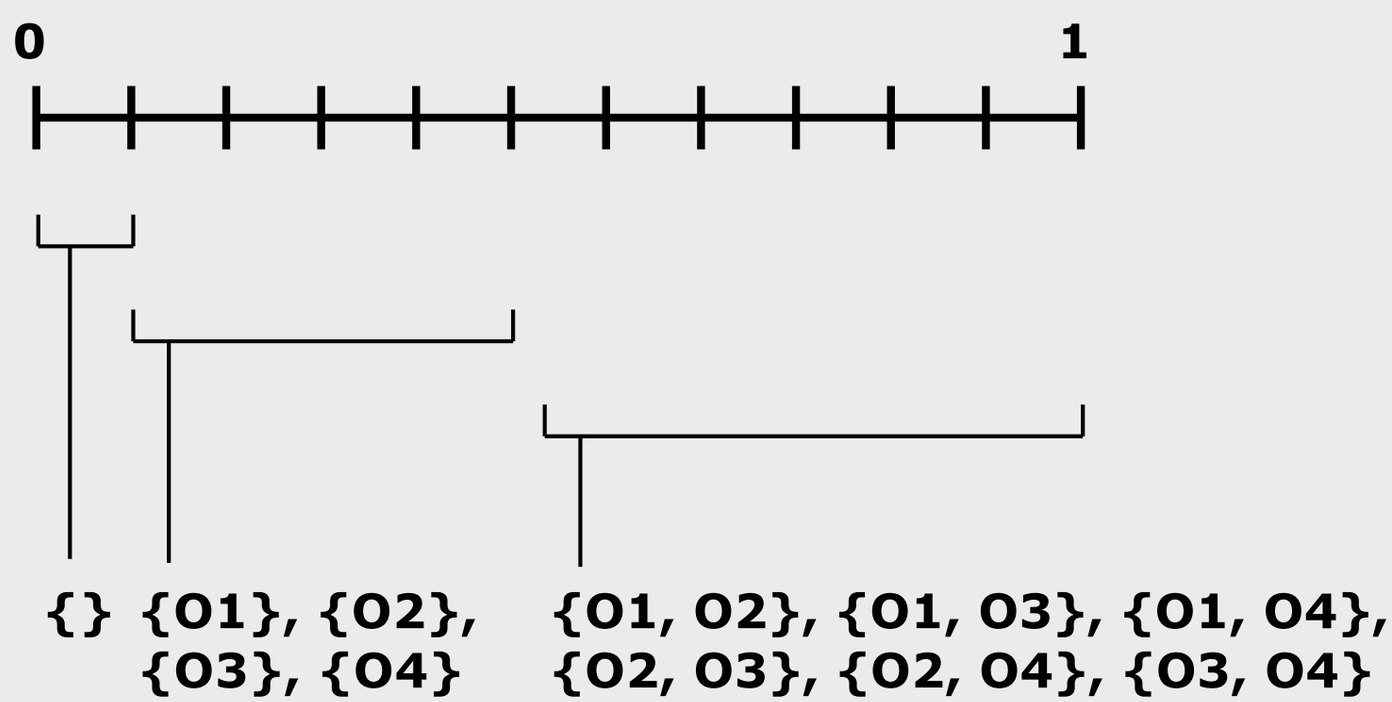
Encoding Decision Variables

Usable opportunities: O1, O2, O3, O4
Science team rule: 0 to 2 must be included in schedule

Usable combinations:

none:	**{}**
one:	**{O1}, {O2}, {O3}, {O4}**
two:	**{O1, O2}, {O1, O3}, {O1, O4},**
	{O2, O3}, {O2, O4}, {O3, O4}

Decision variable encoding to interval [0,1]:



Cluster schedule with multiple objectives

Distribution of objective functional values

Highlighted ("brushed" ranges of interest

Visualization of candidate schedule as DSN tracking activities

Candidate solutions Pareto frontier (4-D projected to 2-D)

Antenna activities for Cluster to avoid

MUSE Next Steps

- Extend initial multi-participant functionality
  - trade-off GUI
  - workflow & notification plug-ins
  - REST-based multi-participant server
- Higher-dimensional multi-objective visualization and manipulation
- Apply to other missions to validate generality of approach

Thank you!