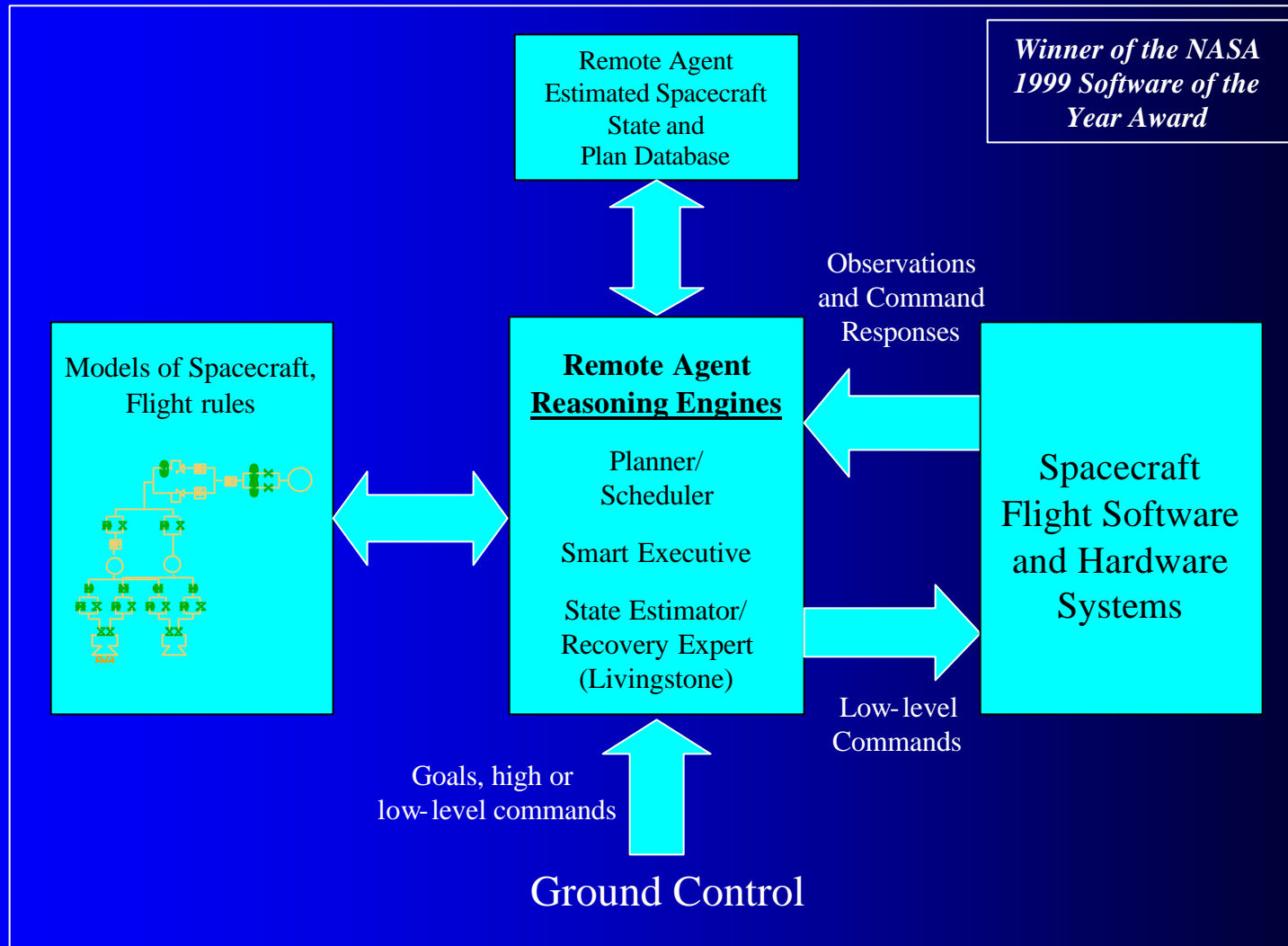
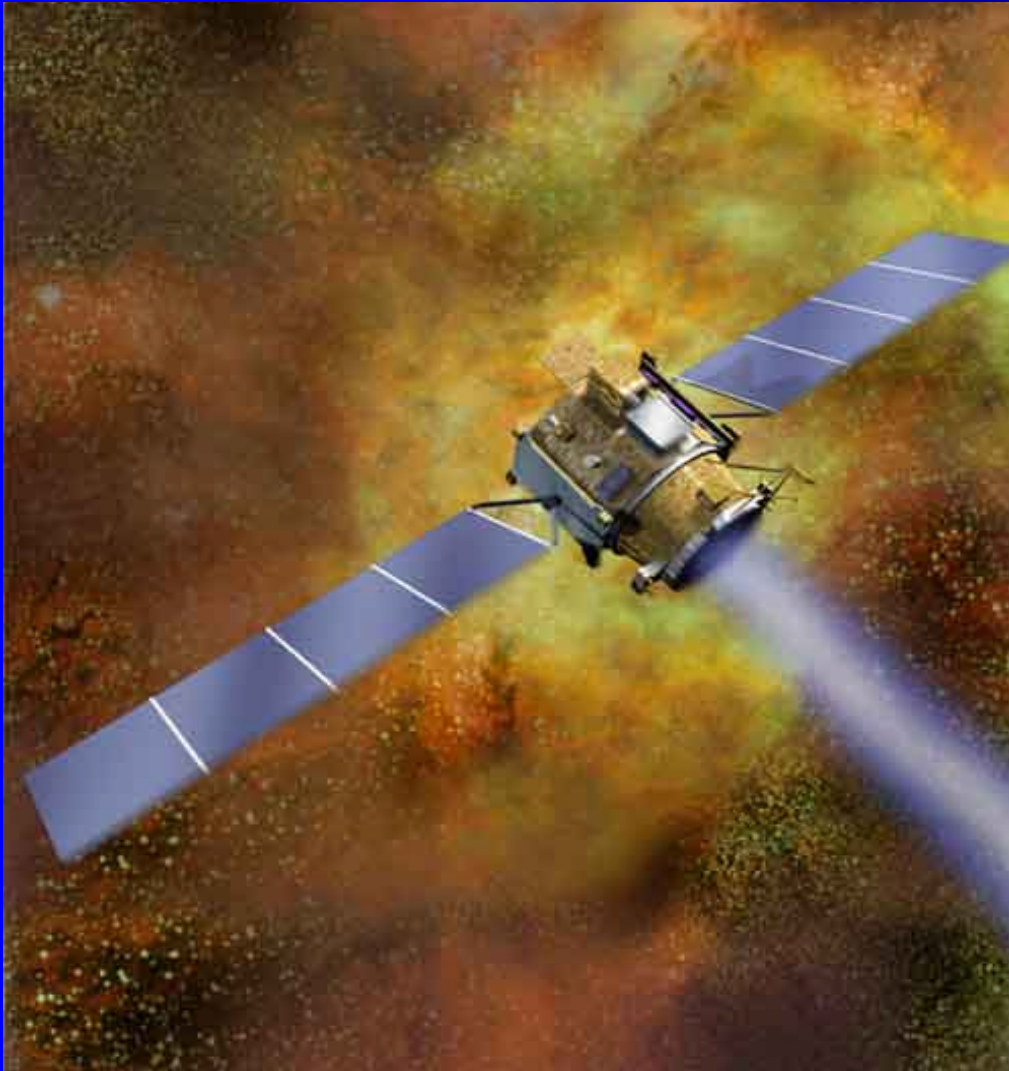


Deep Space One Remote Agent



Deep Space One (DS1)



- Launched 10/98
- Remote Agent Experiment 5/99
- Other technologies flight-validated:
 - Ion Propulsion
 - SCARLET Solar Panels
 - Miniature Integrated Camera & Spectrometer
 - Autonomous Navigation
 - Beacon Monitor
- Current state:
thrusting toward comet Borrelly for 9/2001 encounter

DS1 Remote Agent Architecture

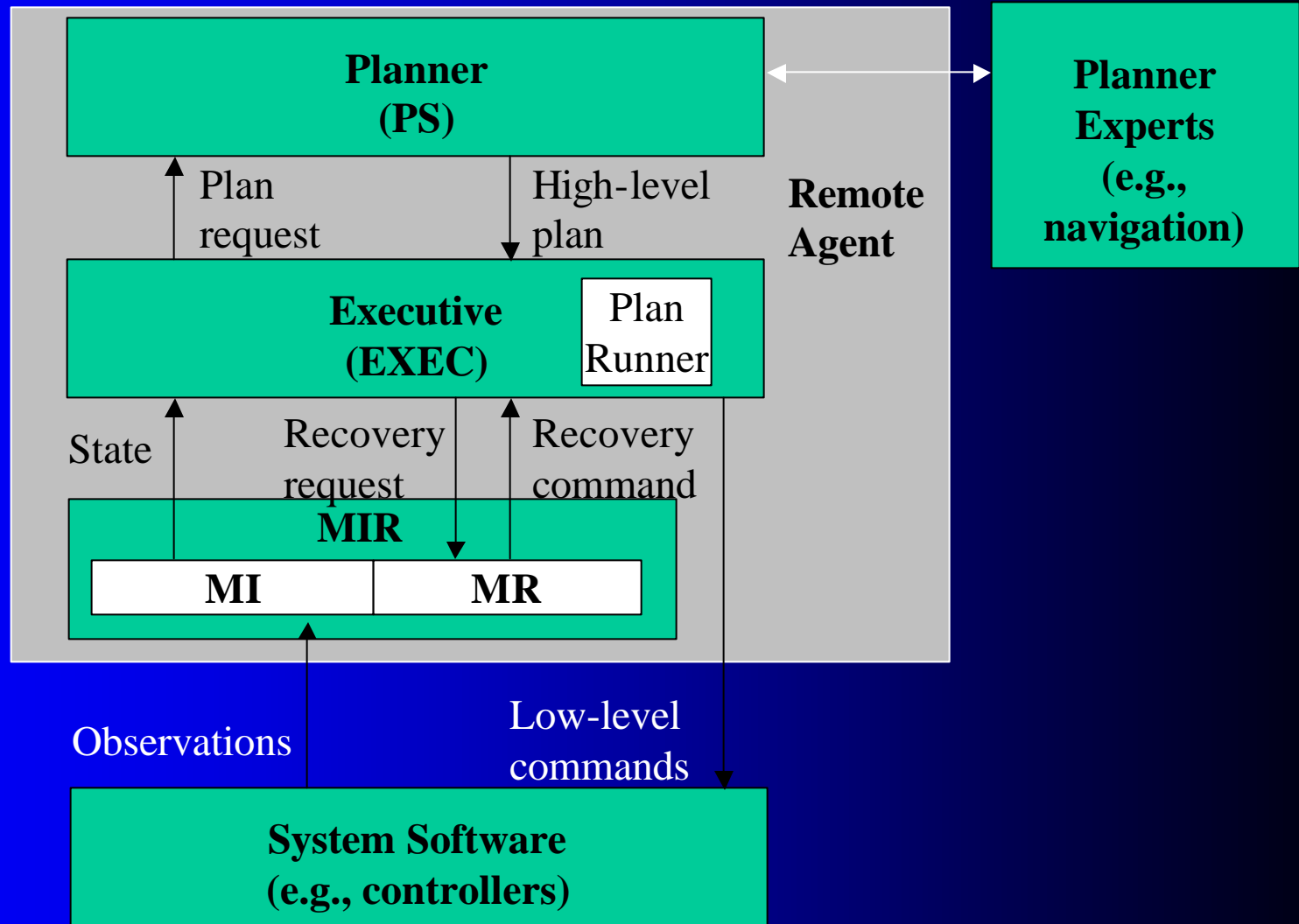
Abstraction Level

High-level declarative model

Medium-level procedural model

Low-level declarative model

Low-level procedures



Domain Requirements

- Achieve diverse goals on real spacecraft
- High Reliability
 - single point failures
 - multiple sequential failures
- Tight resource constraints
 - resource contention
 - conflicting goals
- Hard-time deadlines
- Limited Observability
- Concurrent Activity

Approach

- Constraint-based planning and scheduling
 - supports goal achievement, resource constraints, deadlines, concurrency
- Robust multi-threaded execution
 - supports reliability, concurrency, deadlines
- Model-based fault diagnosis and reconfiguration
 - supports limited observability, reliability, concurrency
- Real-time control and monitoring

Diversity of Goals

- Final state goals
 - “Turn off the camera once you are done using it”
- Scheduled goals
 - “Communicate to Earth at pre-specified times”
- Periodic goals
 - “Take asteroid pictures for navigation every 2 days for 2 hours”
- Information-seeking goals
 - “Ask the on-board navigation system for the thrusting profile”
- Continuous accumulation goals
 - “Accumulate thrust with a 90% duty cycle”
- Default goals
 - “When you have nothing else to do, point HGA to Earth”

Diversity of Constraints

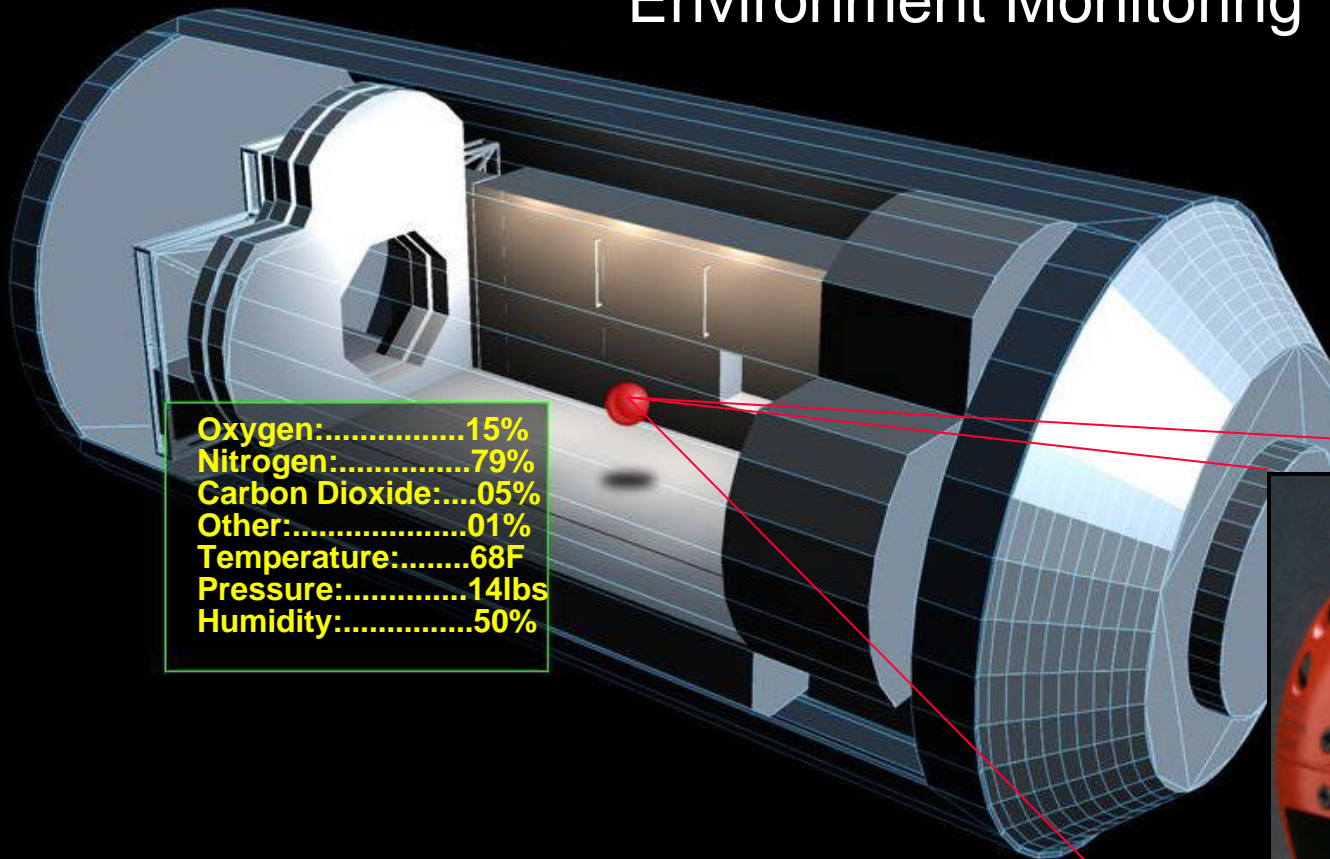
- State/action constraints
 - “To take a picture, the camera must be on.”
- Finite resources
 - power
- True parallelism
 - the ACS loops must work in parallel with the IPS controller
- Functional dependencies
 - “The duration of a turn depends on its source and destination.”
- Continuously varying parameters
 - amount of accumulated thrust
- Other software modules as specialized planners
 - on-board navigator

Deep Space One Remote Agent

- Levels of autonomy supported on DS1 (listed from least to most autonomous mode):
 - single low-level command execution
 - time-stamped command sequence execution
 - single goal achievement with auto-recovery
 - model-based state estimation & error detection
 - scripted plan with dynamic task decomposition
 - on-board back-to-back plan generation, execution, & plan recovery

Personal Satellite Assistant (PSA)

Environment Monitoring



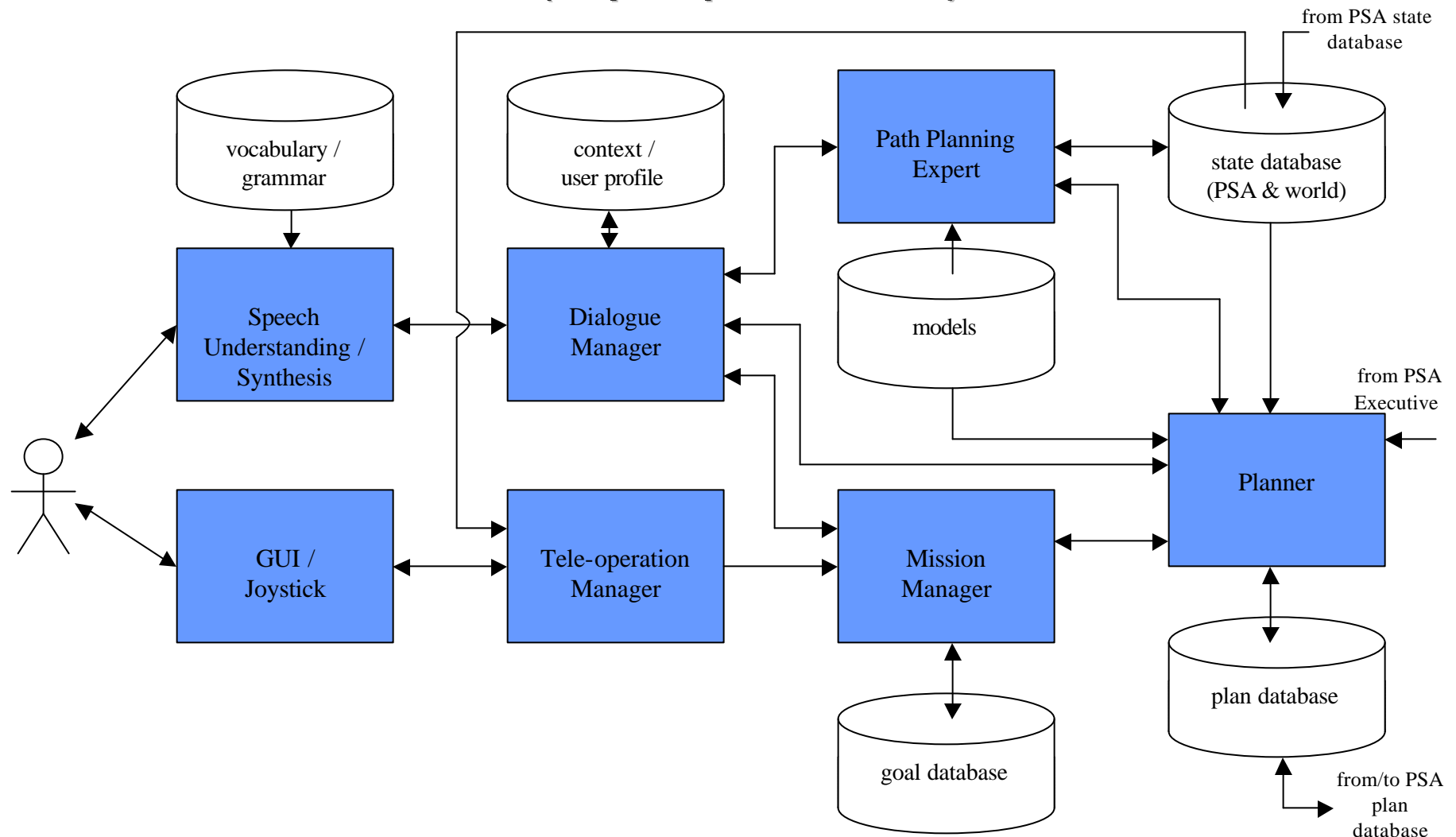
Oxygen:.....	15%
Nitrogen:.....	79%
Carbon Dioxide:....	05%
Other:.....	01%
Temperature:.....	68F
Pressure:.....	14lbs
Humidity:.....	50%

Space Station Module

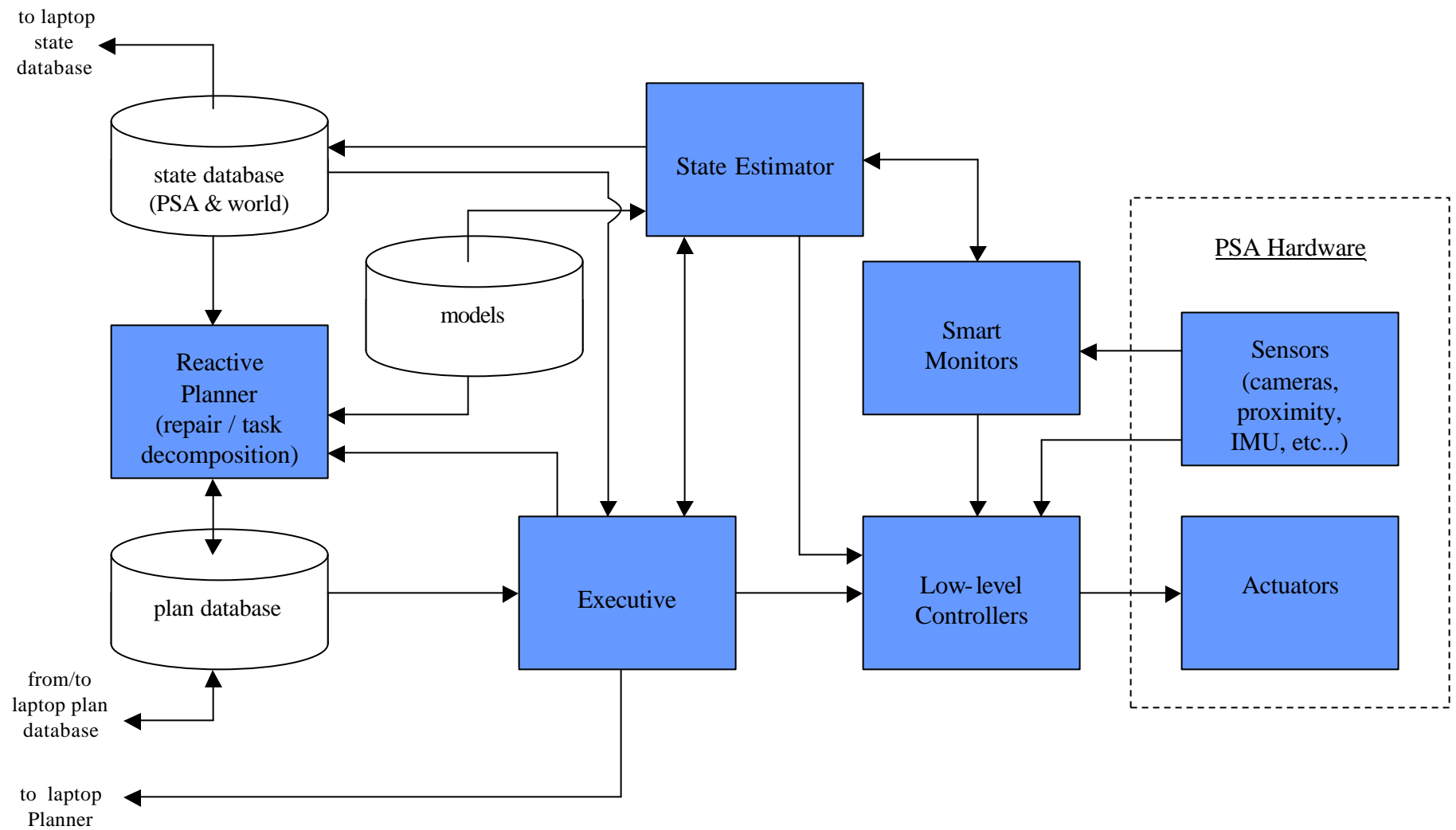
Drawing provided by Boris Rabin



Primary High-Level Control Modules (laptop server)



Primary Low-Level Control Modules (on-board PSA)



PSA Human-Centered Autonomy Requirements

- Humans dynamically modify plans during generation and execution
 - direct control can always be taken by human
- Humans dynamically act as sensors and actuators
- Humans dynamically modify domain models
- Humans communicate with system using limited natural-language context-sensitive grammar
- Autonomous system state, goals, models, and plans visible to humans
- System interacts with humans in its environment
- Dynamically modify plans as new goals are added, models change, human roles change, or plans fail