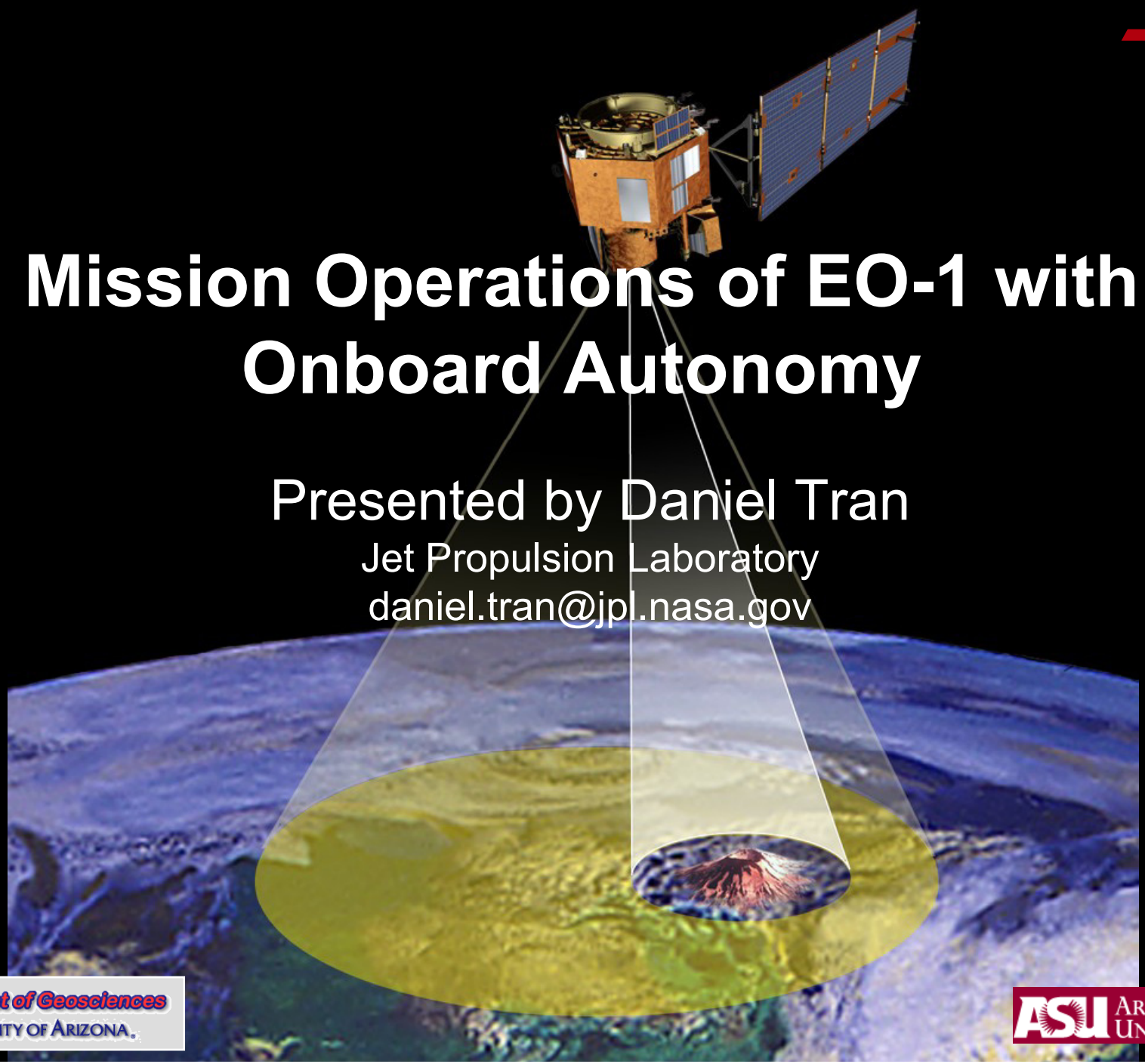

Mission Operations of EO-1 with Onboard Autonomy

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Outline

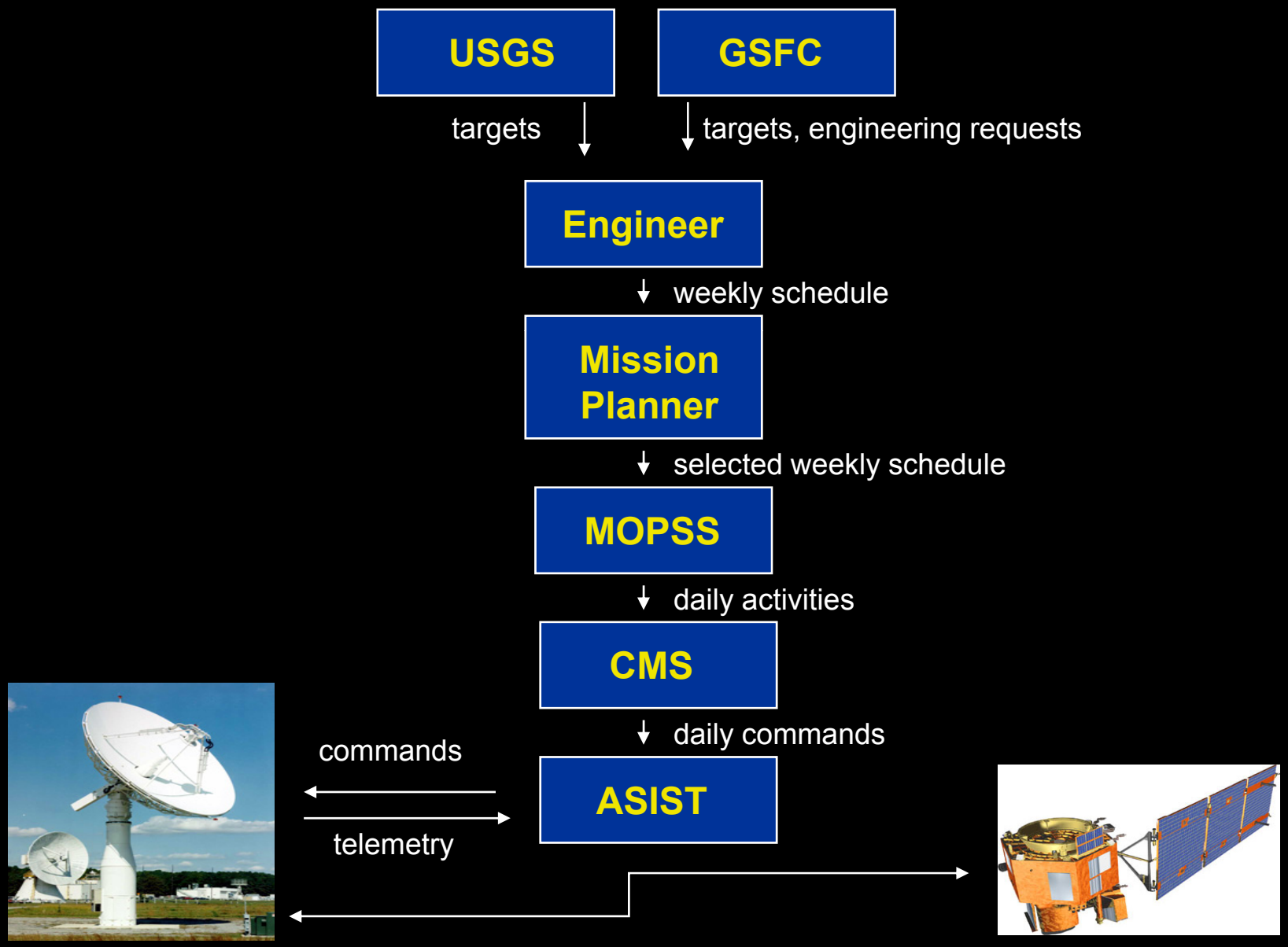
- Earth Observing-1 spacecraft
- Past Operations Flow
- The Autonomous Sciencecraft Experiment
  - Mission Scenario
  - Flight Software Architecture
  - Onboard Planning
- Present Operations Flow
- Earth Observing Sensorweb
- Current Status

Earth Observing-1

- **Part of the New Millennium Program**
- **Management and Operations**: Goddard Space Flight Center (GSFC)
- **Launch:** November 21, 2000
- **Orbit**: Low-Earth
- **Instruments**: Advanced Land Imager (ALI) and Hyperion Hyperspectral Imager (HSI)
- **Main Processors**: 2 Mongoose V R3000 12 MHz with 256 MB RAM each, 45 Gbit SSR

Past EO-1 Operations

Past Operations Flow



Limitations of Past Operations

- Priority observation requests require 1-2 days of lead time
- Modifications to the baseline plan are difficult as spacecraft command sequences are static
- Manual scheduling of observations and station contacts tedious
- Turnaround time for science data days or weeks after requests
  - Short-lived science opportunities may be missed

The Autonomous Sciencecraft Experiment

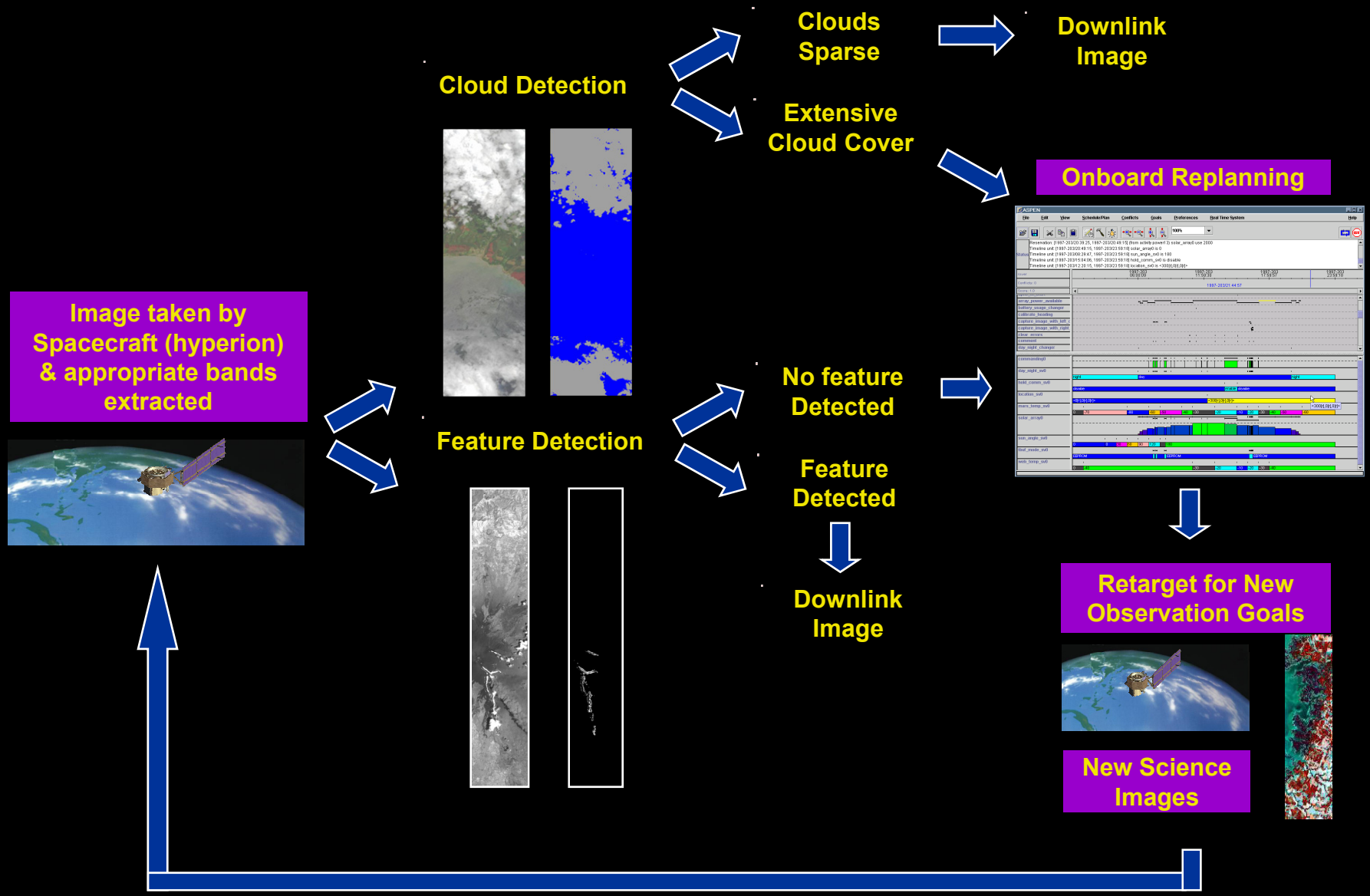
Autonomous Sciencecraft Experiment

- New Millennium Space Technology-6 (ST-6) Project
- Led by the Jet Propulsion Laboratory (JPL)
- Teamed with EO-1 in early 2003

- Flight (onboard autonomy)
  - Science algorithms for image analysis
  - Robust execution (SCL)
  - Planning and scheduling (CASPER)
- Ground (automation)
  - Automated Planning and Scheduling (ASPEN)
  - WWW interface

ASE Concept

ASE on EO1 Mission Scenario



7 May 2004 ASE monitors Mount Erebus

ASE images Erebus (Night) 13:40 GMT

} +10 min

ASE initiates band extraction

} +28 min

ASE runs thermal classifier

} +29 min

THERMAL TRIGGERED

7 May 2004 ASE monitors Mount Erebus

ASE images Erebus (Night) — 13:40 GMT

} +10 min

ASE initiates band extraction

} +28 min

ASE runs thermal classifier

} +29 min

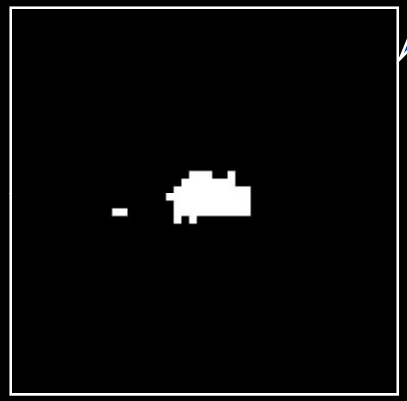
THERMAL TRIGGERED

Onboard planner modifies baseline schedule to image Erebus

} +20 min

Thumbnail downlinked (S-band) — 15:58 GMT

ASE Onboard Thermal Classifier Thumbnail (Erebus Night)



+ 2 hours 18 minutes

7 May 2004 ASE monitors Mount Erebus

ASE images Erebus Night — 13:40 GMT

} +10 min

ASE initiates band extraction

} +28 min

ASE runs thermal classifier

} +29 min

THERMAL TRIGGERED

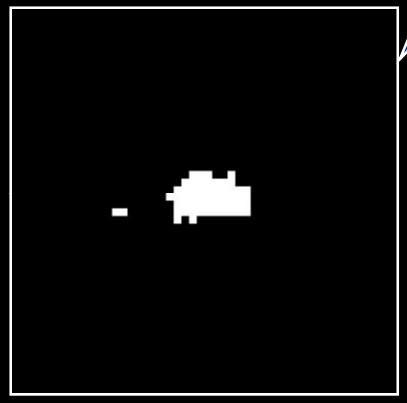
Onboard planner modifies baseline schedule to image Erebus

} +20 min

Thumbnail downlinked (S-band) — 15:58 GMT

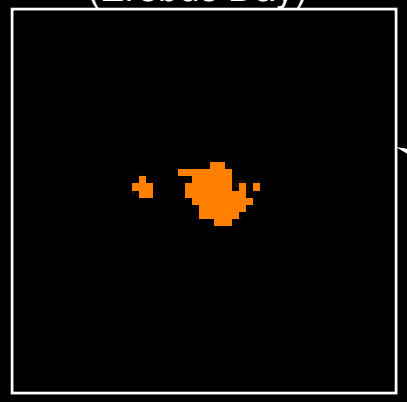
ASE images Erebus again — 20:10 GMT

ASE Onboard Thermal Classifier Thumbnail (Erebus Night)



+ 2 hours 18 minutes

ASE Onboard Thermal Classifier (Erebus Day)



+ 6 hours 30 minutes

7 May 2004 ASE monitors Mount Erebus

ASE images Erebus Night — 13:40 GMT

} +10 min

ASE initiates band extraction

} +28 min

ASE runs thermal classifier

} +29 min

THERMAL TRIGGERED

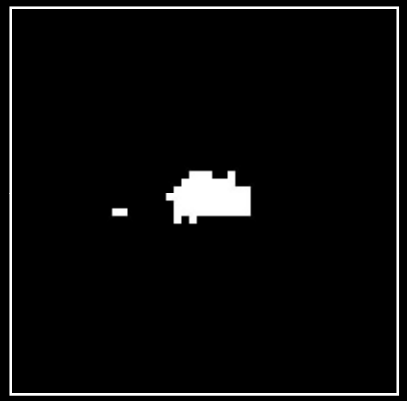
Onboard planner modifies baseline schedule to image Erebus

} +20 min

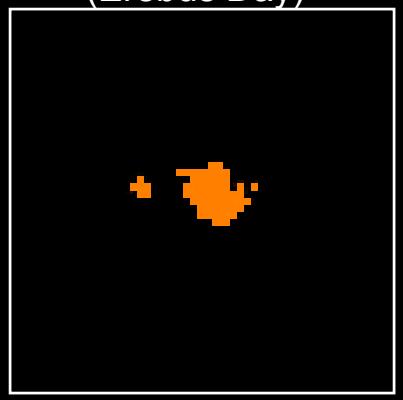
Thumbnail downlinked (S-band) — 15:58 GMT

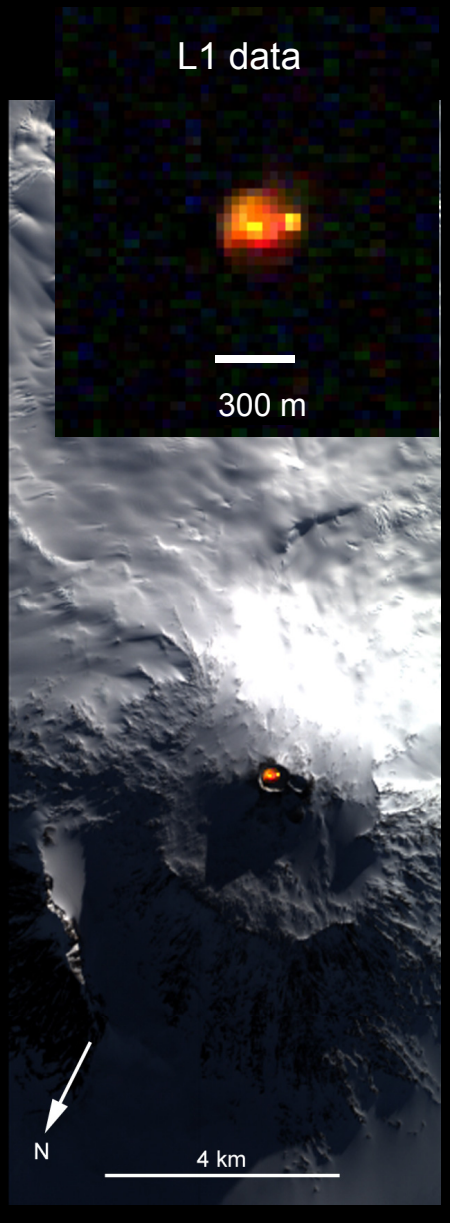
ASE images Erebus again — 20:10 GMT + 06:30

ASE Onboard Thermal Classifier Thumbnail (Erebus Night)



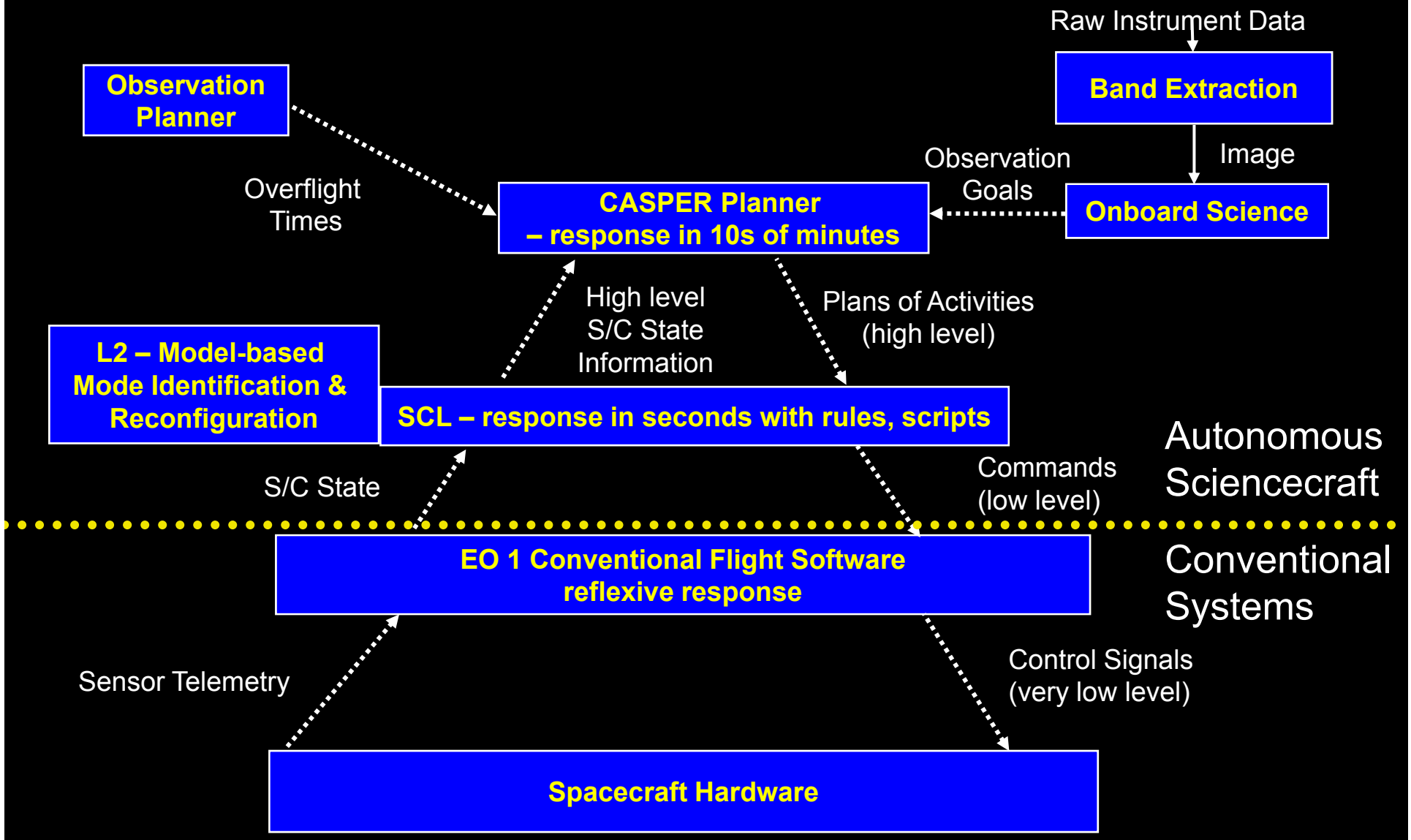
ASE Onboard Thermal Classifier (Erebus Day)





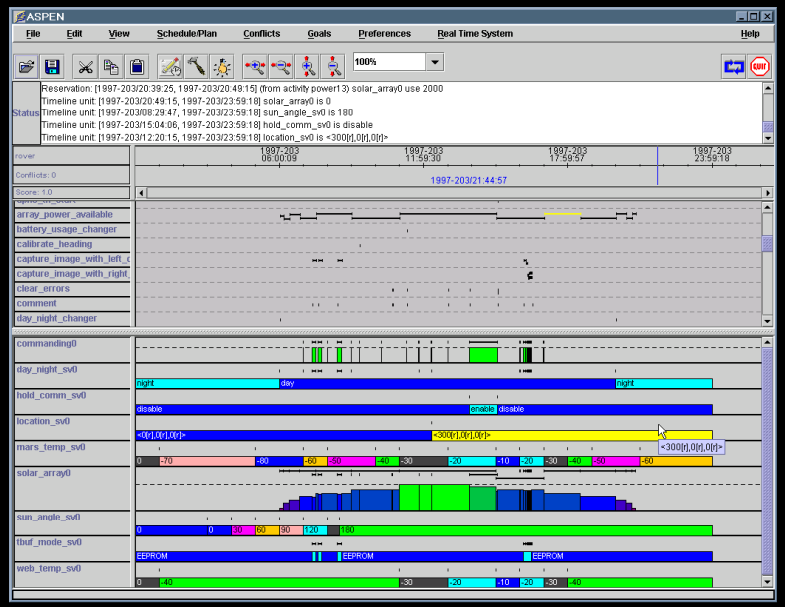
- **ASE enabled rapid notification of volcanic event**
- **ASE enabled rapid re-imaging of this event**
- **Autonomous response as normal operations!**
  - **Highest leverage for deep space missions**

ASE Flight Software Architecture



How do we autonomously update the baseline schedule?

Onboard Planning and Execution



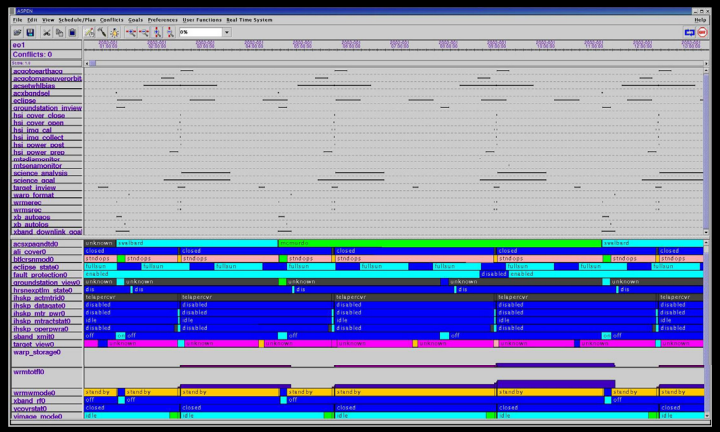
CASPER Onboard Replanning

Goals:

science requests,
downlink requests,
maneuver requests

Constraints:

memory,
power



Activity Plan:

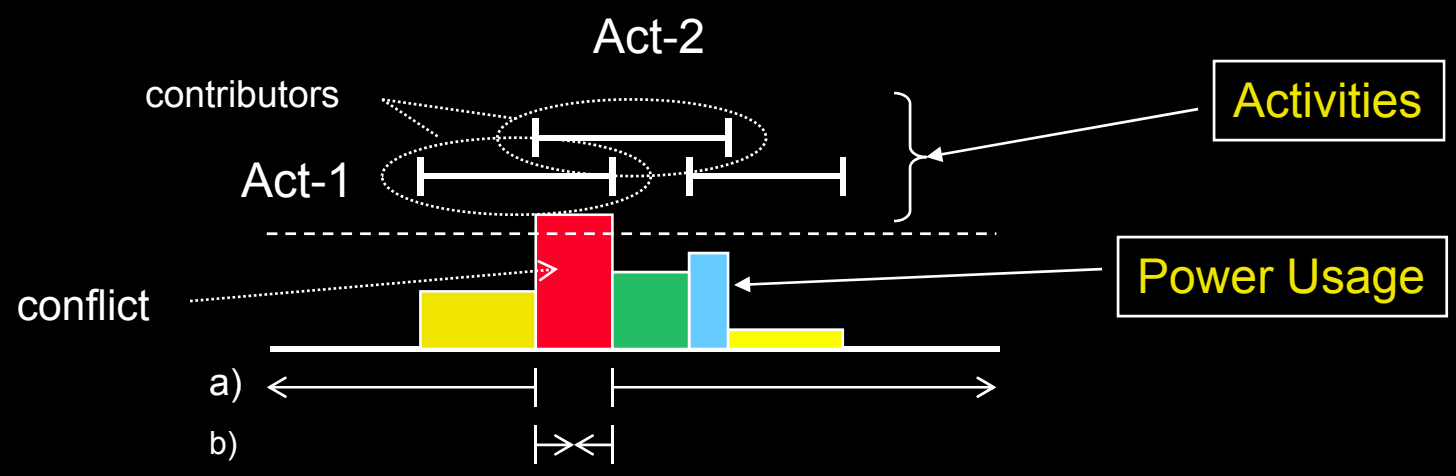
2003:233:16:49:57 CMD BIAS REACTION WHEELS
2003:233:17:56:57 CMD SLEW TO TARGET
2003:233:18:07:06 CMD POWER ALI
2003:233:18:07:06 CMD POWER HSI
2003:233:18:07:16 CMD SET HSI PARAMETERS
2003:233:18:11:06 CMD SET ALI PARAMETERS
2003:233:18:17:16 CMD SSR IN REC MODE
2003:233:18:17:54 CMD ALI IN IMAGING MODE
2003:233:18:17:55 CMD HSI IN IMAGING MODE
...

CASPER Uses Model of Activities

Science Data Collect Activity	
Resources	uses 30 W power; uses <variable> memory
State Constraints	requires ACS state to be “Fixed Attitude”
Required Activities	Decompositions dark calibration image before dark calibration image after

CASPER uses these activity models to determine how activities will affect spacecraft state and resources

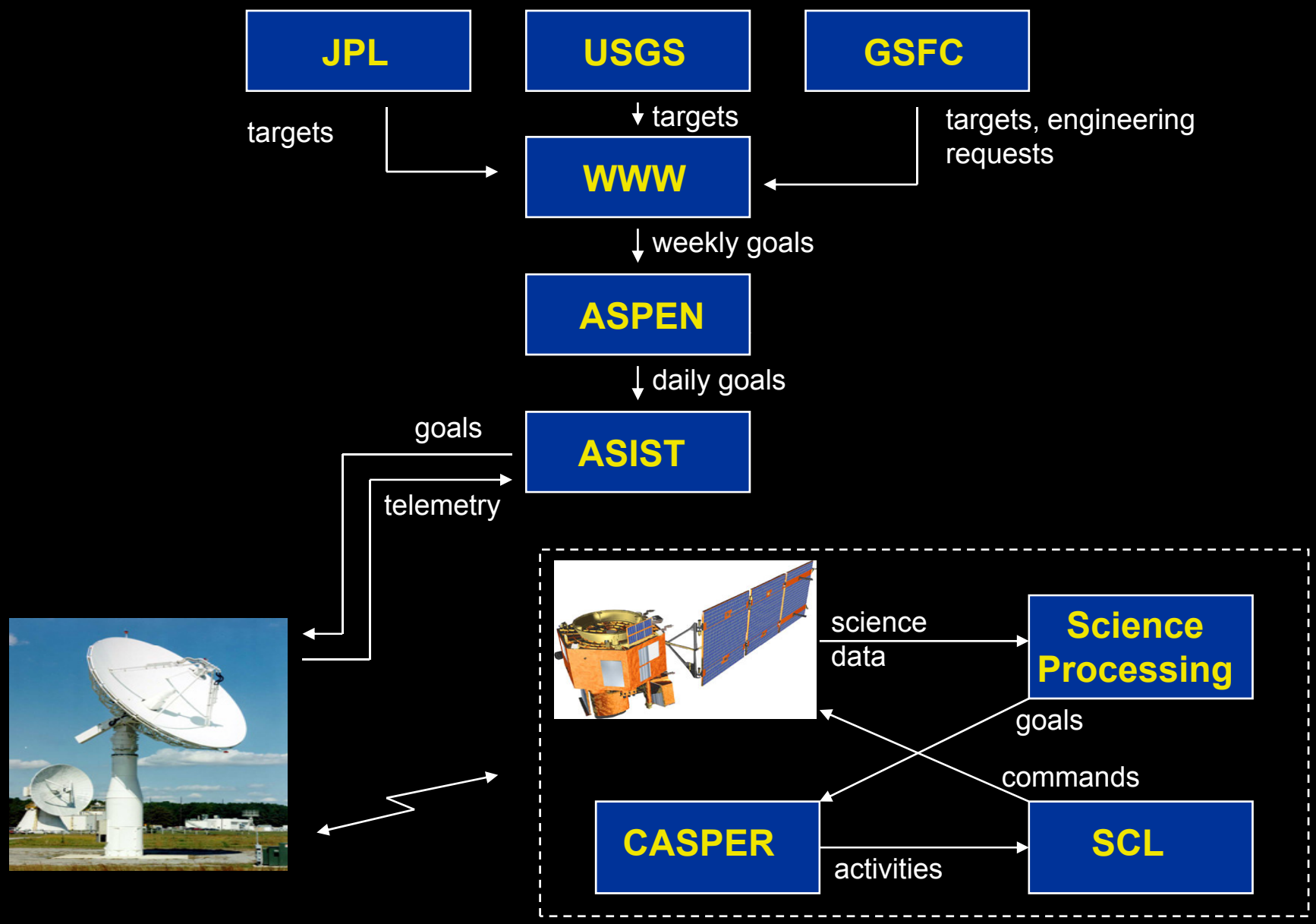
Activities, Constraints, Repairs

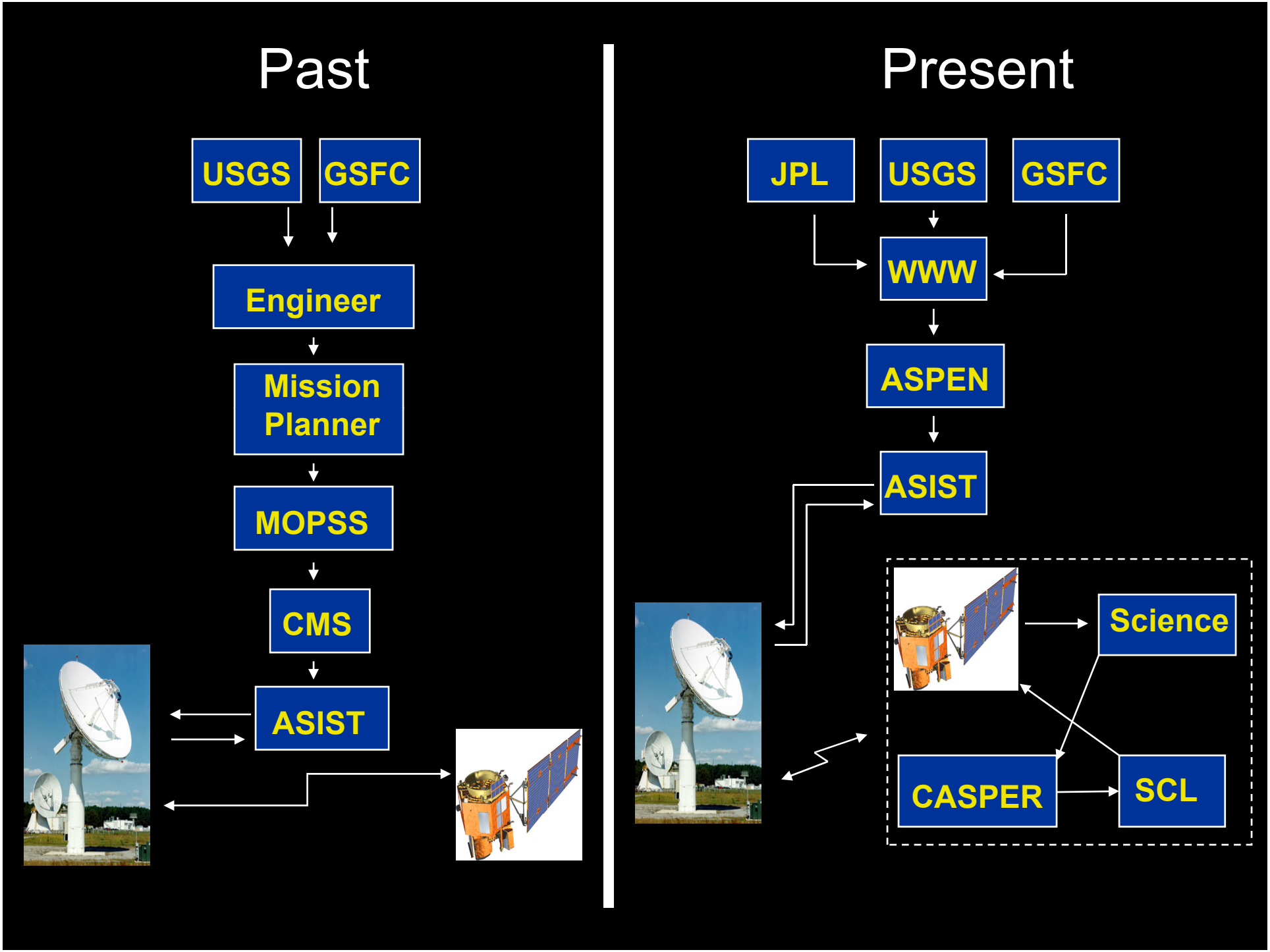


	General Property	Example
Constraint	Property that must hold for plan to be valid	Must always use less power than available
Conflict	Violation of a constraint	Current plan uses more power than available over (b)
Repair Method	Modification to plan that may remove conflict	Delete activity using power during conflict (b)
Repair Choice	Which activity to delete	Delete largest user?

Present EO-1 Operations

Current Operations Flow




Past
USGS
GSFC
Engineer
Mission Planner
MOPSS
CMS
ASIST
Present
JPL
USGS
GSFC
WWW
ASPEN
ASIST
Science
CASPER
SCL

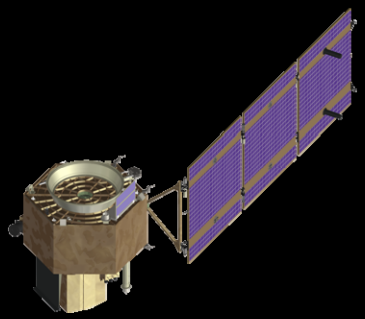
Key Differences

- Scenes and ground contacts are selected automatically based on scene priorities
- World Wide Web interface for requesting and acquiring observations
- High-level scene and contact “goals” are uploaded to the spacecraft instead of detailed command sequences
- Execution sequence can be automatically changed on-board
- Priority observations can be requested and acquired within hours
- Science data is immediately available for analysis on-board compared to days or weeks

Earth Observing Sensorweb

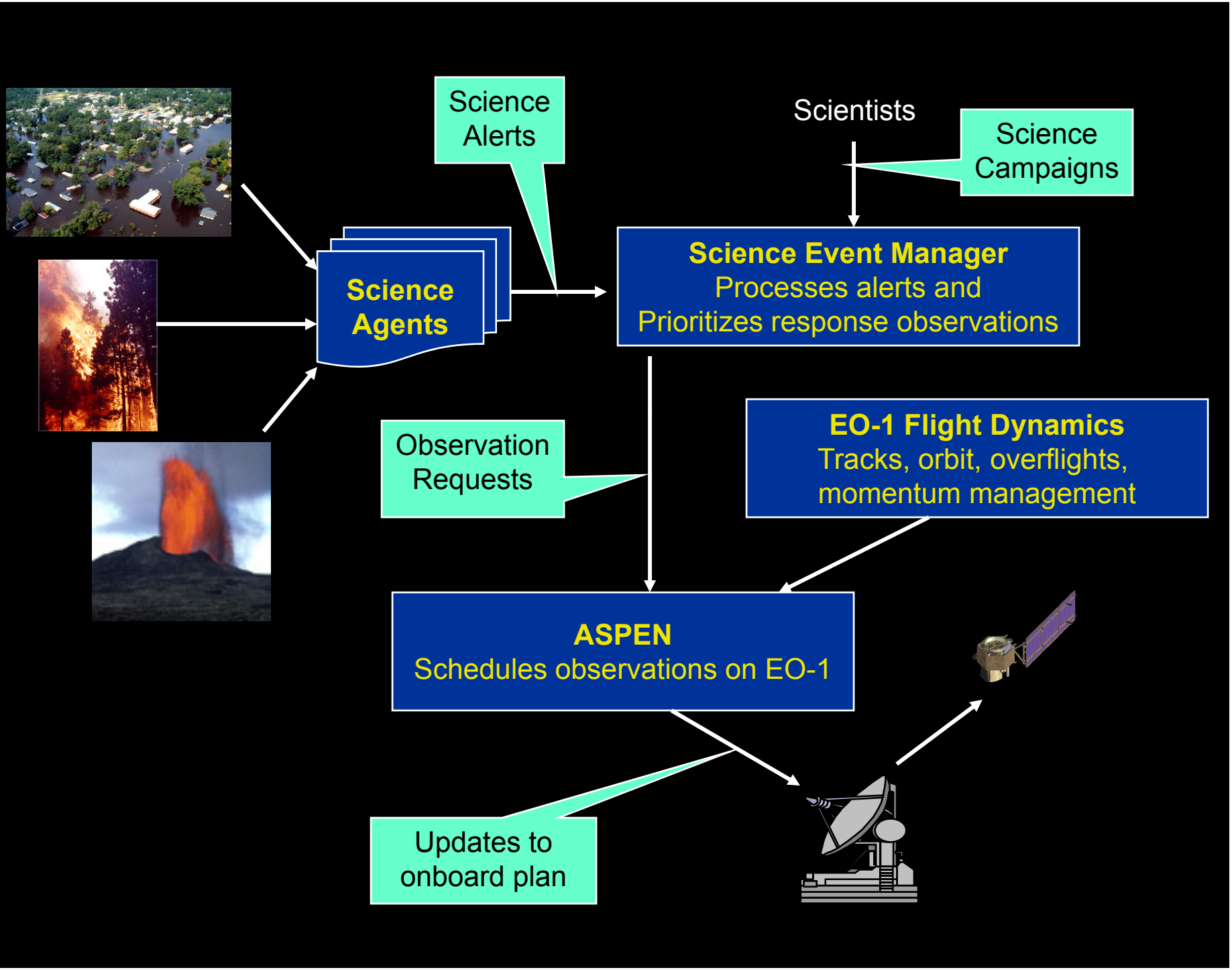
Earth Observing Sensorweb

Re-tasking



EO-1

Triggers so far: Wildfires, Floods, Volcanoes (thermal, ash), Ice/Snow, in-situ sensors, modified by cloud cover


Science Alerts
Scientists
Science Campaigns
Science Agents
Science Event Manager
Processes alerts and
Prioritizes response observations
Observation Requests
EO-1 Flight Dynamics
Tracks, orbit, overflights,
momentum management
ASPEN
Schedules observations on EO-1
Updates to onboard plan

ASE Current Status

ASE has achieved 100% of its Experiment
Full Success Criteria as of May 14, 2004

- This includes multiple (5 each) successful:
  - On-orbit autonomous detection & response observations
  - Onboard data editing
- Current count 6500+ autonomous data collects with over 700 of image, analyze, and retarget data collects
- Acquired over 950 sensorweb triggered observations

- As of November 2004, ASE is now in use as baseline operations for the remainder of the mission.

ASE Information/Acknowledgements

- Web Site: ase.jpl.nasa.gov
- Team:
  - Steve Chien (Principal Investigator), Rob Sherwood (Experiment Mgr)
  - JPL: Daniel Tran (Software Lead), Rebecca Castano (Onboard Science Lead), Ashley Davies (Science Lead), Gregg Rabideau, Ben Cichy, Nghia Tang
  - Interface & Control Systems (ICS): Darrell Boyer, Jim Van Gaasbeck
  - Univ. of AZ: Victor Baker, Felipe Ip, James Dohm
  - ASU: Ronald Greeley, Thomas Doggett
  - GSFC: Dan Mandl (Mission Director), Stu Frye (Systems Engineer, Mitretek), Jerry Hengemihle, Scott Walling & Bruce Trout (Microtel), Jeff D'Agostino (Hammers), Seth Shulman (Operations Lead, Honeywell), Lawrence Ong (SSAI), Stephen Ungar (EO-1 Scientist), Thomas Brakke
  - MIT LL: Michael Griffin, Hsiao-hua Burke, Carolyn Upham

- ASE Sponsor:
  - New Millennium Program, ST-6 Project

- Technology Development:
  - Intelligent Systems Program
  - CETDP, Thinking Systems Thrust
  - Interplanetary Network Technology Program