# www.jpl.nasa.gov


**Leonard Reder**

**reder@jpl.nasa.gov**


**28 April 2017**

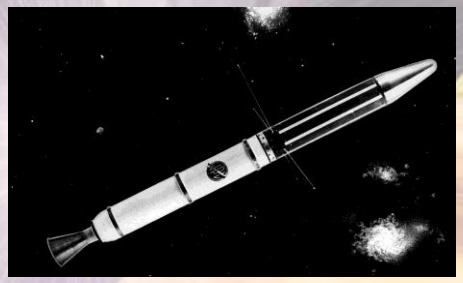

Jet Propulsion Laboratory,
California Institute of Technology


## From Analog/RF Engineer to Software Engineer: 21 Years working at the Jet Propulsion Laboratory with a 14 year detour working outside the lab


Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not constitute or imply its endorsement by the United States Government or the Jet Propulsion Laboratory, California Institute of Technology.

© 2017 California Institute of Technology. Government sponsorship acknowledged.

- Spread out over about 176 acres
- Approximately $2.2 B Business Base ($1.6 B in 2009)
- Over 5000 employees and contractors
- Under NASA contract but managed by CalTech
- Supported by proposals to do work
- About 15% to 20% of work is non-NASA (Military, Civil, etc.)
- JPL is a non-profit organization (FFRDC)
- The lab has been around for about 78 years

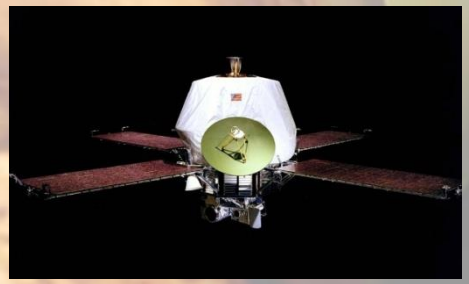


1st U.S. satellite
Explorer 1 - Jan 28, 1958

1st close-up images of another planet
Mariner 4 to Mars - Nov 1964

1st fly-bys of Neptune and Uranus
Voyager 2 - 1986 & 1989

1st U.S. spacecraft to the moon
Ranger 7 - Jul 28, 1964

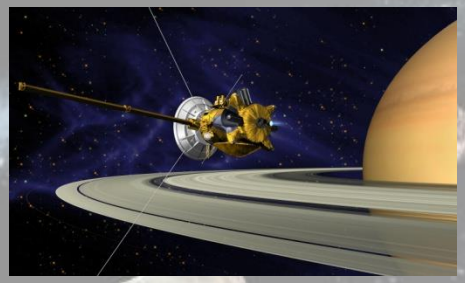


1st orbiter at another planet
Mariner 9 to Mars - May 1971

1st orbiter at Jupiter
Galileo 1979 - 1989

1st planetary mission
Mariner 2 to Venus – Dec. 1962

1st gravity assist mission
Mariner 10 to Venus - Feb 5, 1974



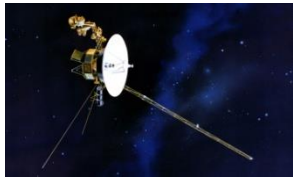
1st orbiter at Saturn
Cassini 2004 - present

Cal Poly Talk
(reder@jpl.nasa.gov)

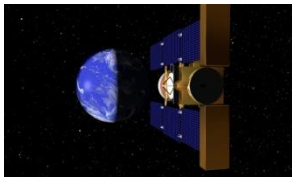
# Mars Rovers

First Rovers on Mars:

1. Curiosity Mar Science Laboratory – 2012
2. Spirit & Opportunity Mar Exploration Rovers – 2004
3. Mars Pathfinder - 1997

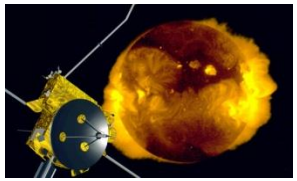


Voyagers 1 & 2

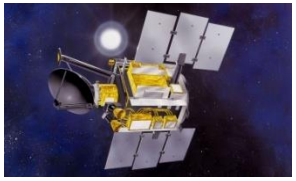


Stardust

Galaxy Explorer

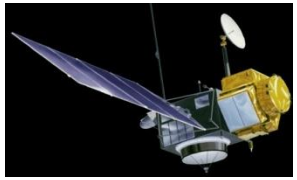


Ulysses

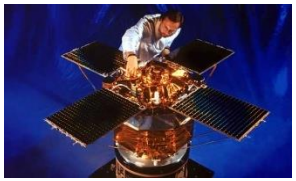


QuikScat

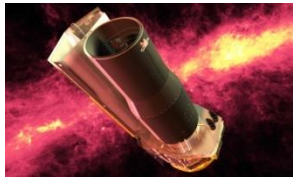
Spirit & Opportunity



Topex/Poseidon

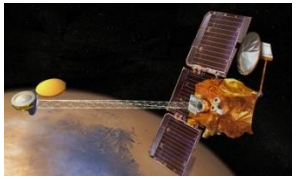


ACRIM



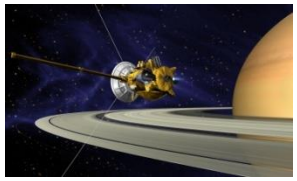
Spitzer Space Telescope

Mars Global Surveyor



Mars Odyssey

Mars Reconnaissance Orbiter



Cassini

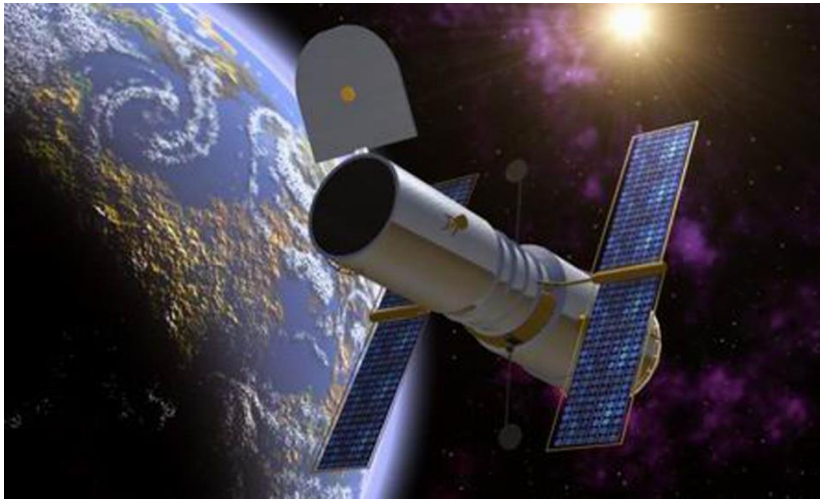
Jason

CloudSat

On behalf of NASA, JPL is responsible for operating 15 spacecraft, 2 Mars rovers, and numerous science instruments that today are surveying the solar system and beyond.

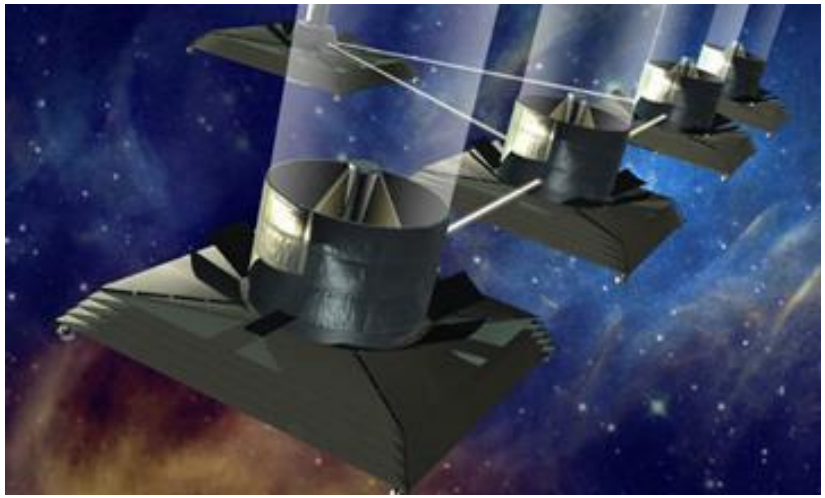
Cal Poly Talk
(reder@jpl.nasa.gov)

Keck Observatory (Interferometer)



Hubble Space Telescope

PlanetQuest SIM
Mission Concept



Planet Finder (TPF)
Mission Concept

# My Background

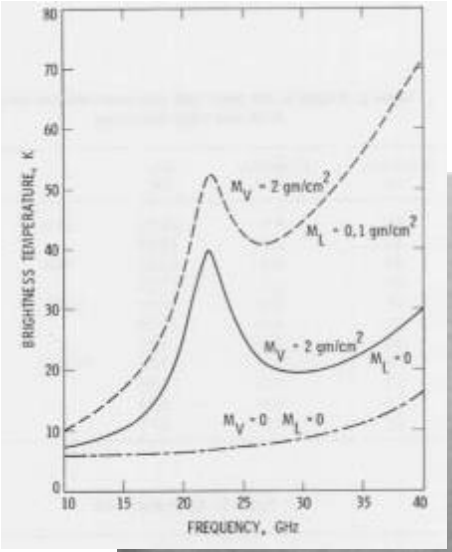
- BSEL Degree Cal Poly San Luis Obispo, CA. (1981)
- Joined JPL in radio Interferometry and adv. receiver research groups (1982-1985)
- MSEE *University of Southern California (1990)*
  - ✓ *Concentrated in DSP and Image processing*
- 16 years outside JPL (1985-1999):
  - ✓ Computer start up company (Symbolics).
  - ✓ Navy R&D real-time detection processors.
  - ✓ Worked for a film studio (Warner Bros.)
- Returned to JPL to work in the optical Interferometry group (1999)
  - ✓ Real-time software engineer for Keck Interferometer Project
    - Fast Delay Line Control, Sequencing, and Science Automation
- Transferred to JPL Flight Software (FSW) section (2007)
  - ✓ Mars Science Laboratory (Curiosity) flight/ground interface lead
  - ✓ Too many small tasks to count
  - ✓ Currently in Small Scale FSW Group working DoD and R&D tasks

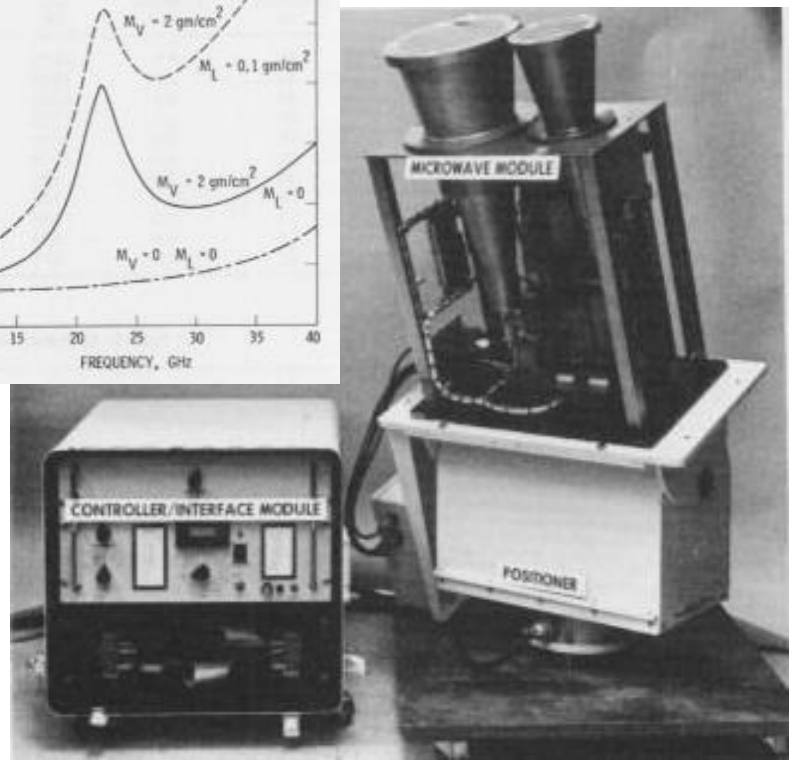
# Deep Space Network Antenna (70 meter diameter)

- Three locations
  - 120 deg. Apart
  - Goldstone, CA.
  - Madrid, Spain
  - Canberra, Australia
- 1966 support of Mariner 4
- Used to track Apollo and every major robotic planetary mission
- Other Science:
  - Interferometry

http://deepspace.jpl.nasa.gov/dsn/

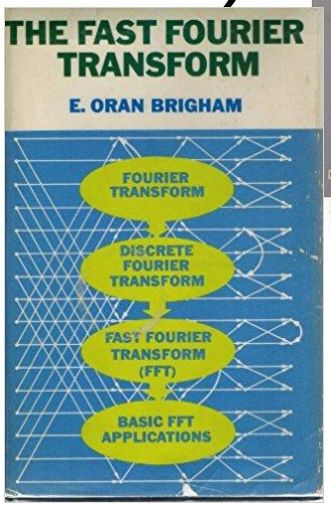
# First Experiences At JPL (1982-1985)




**Dual Channel Water Vapor Radiometer With cover removed from Microwave package**

- 22 & 32 Ghz measurement channels
- Water Vapor Delay produced for VLBI
- Z80 based pointing & data acquisition of noise measurement's



**Joined a Adv. Receivers Research Group in 1983**

- Advanced high dynamics GPS receiver demonstrations
- Advanced Doppler ranging of projectiles for war game scoring
- Basically spent the next 2 years developing FFT codes for TMS32010 prototype hardware.

# Symbolic's (1985-1988)

- Hired by Symbolics Graphics Div. as Video Analogy/Digital Board Designer
  - First hardware pan/zoom FPGA
  - First HDTV processing (2K line displays)
  - Bit mapped color graphics interfaces
  - Video genlocking
- Symbolics .com domain registered on March 15, 1985 is first computer domain in the world
- First commercially available workstation
- Optimized to run LISP language
- Spin-off from the MIT AI lab

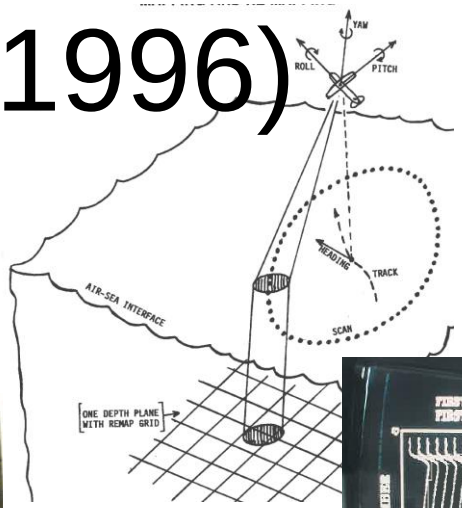
Stanley & Stella
Siggraph 87 Demo

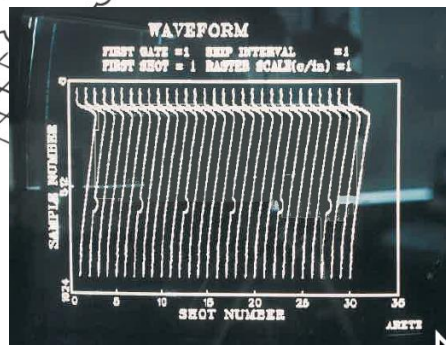
Symbolics 3640 G-Machine

# Arete (1988-1996)

- Hired as a Real-Time Processor Engr.
- **Goal to demonstrate companies algorithms within field applications**

U. S. Navy P3 Aircraft




Laser Radar scan patter and return waveforms

**Today all this in RaspberryPi**

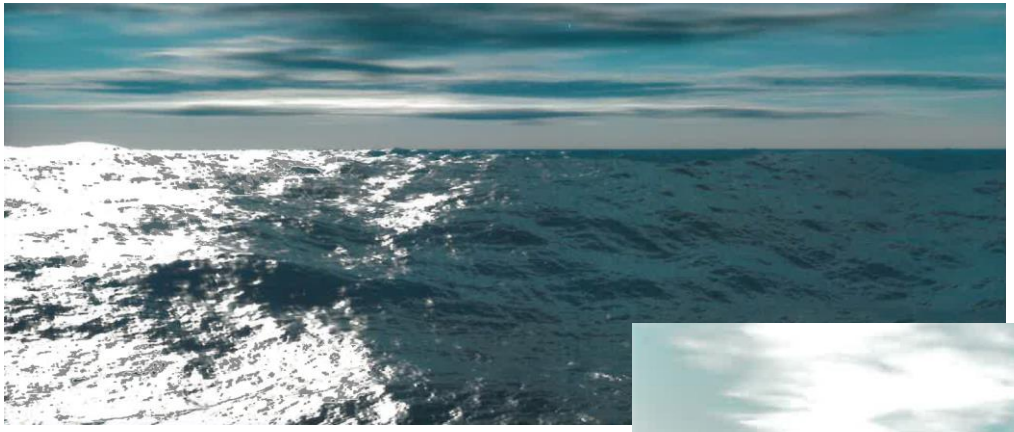
Image of a mine-like object detected by matched-filter algorithm

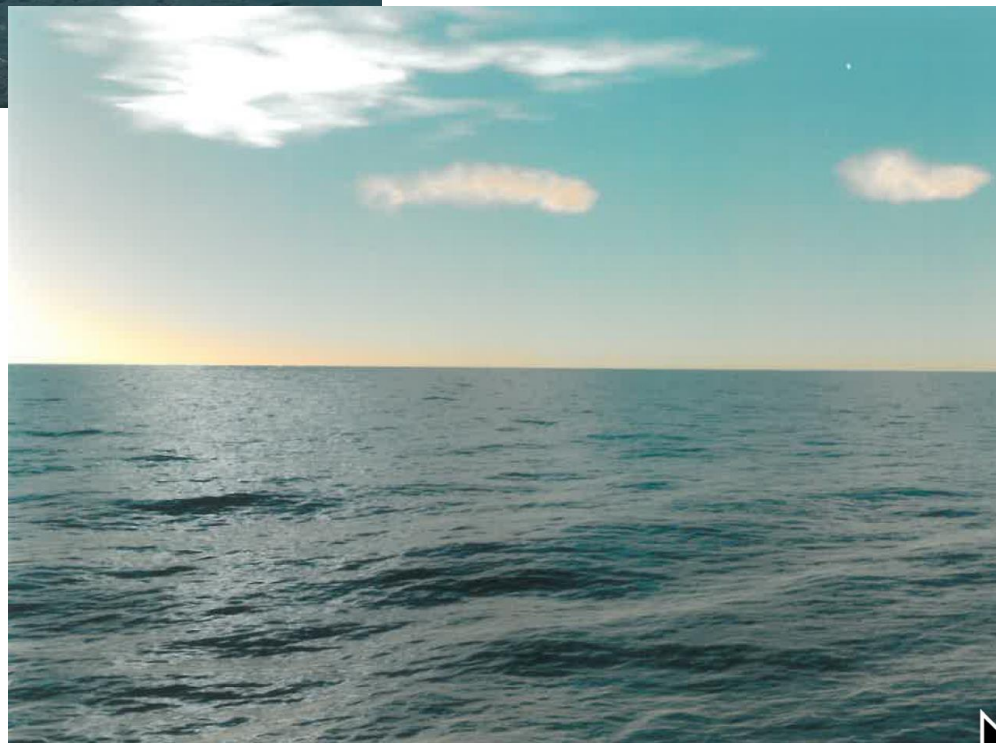
**LIDAR Real-Time Detection processor and display Integrated into P3**

Integration & test in Real-Time processing Laboratory, Sherman Oaks, CA.

Cal Poly Talk
(reder@jpl.nasa.gov)

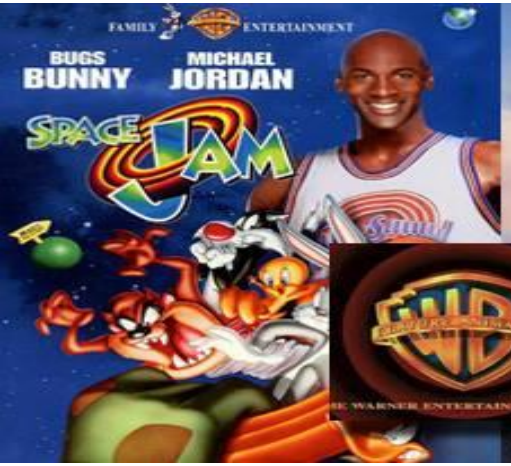
# Arete (1988-1996)





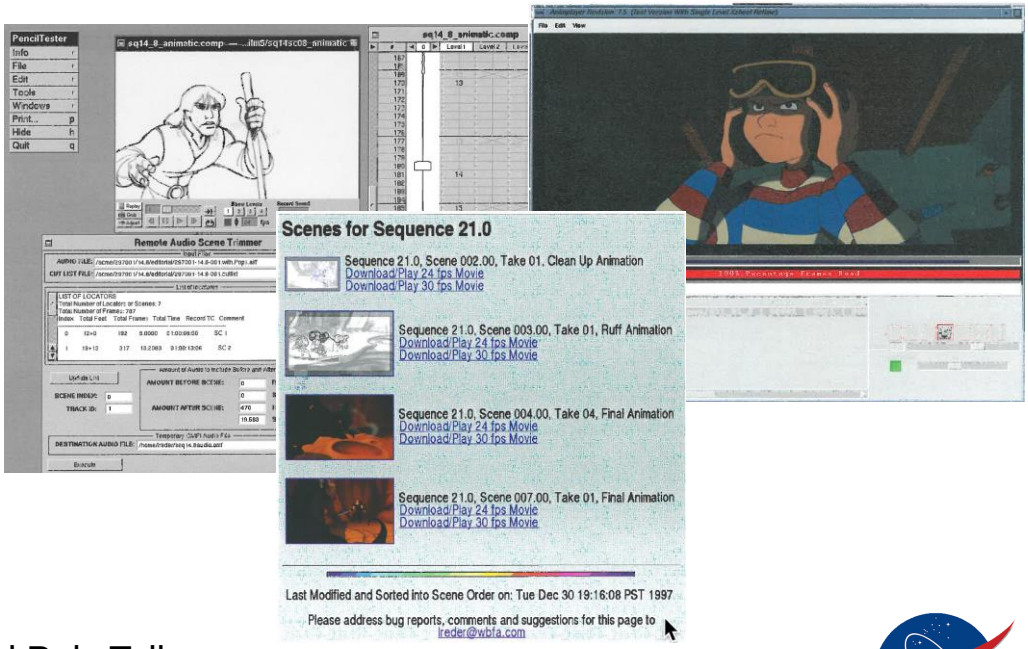
- Supported IR simulation and animation of demo movies
- This is what happens when the wavelength with a physics based simulator is tuned to visible wavelength
- Sold technique to motion picture industry
  - Free Willy
  - Titanic

# Warner Bros. Feature Animation Div. (1996-1999)



Hired as a Post-Production Technology Lead Engineer

- Dual reporting: WBFA Technology Director, Post-production supervisor, and Editor of each production
  - SW tools
  - Processes
- Media data flow
- Film recording
- Digital dailies playback
- Last stop for technical problems solutions



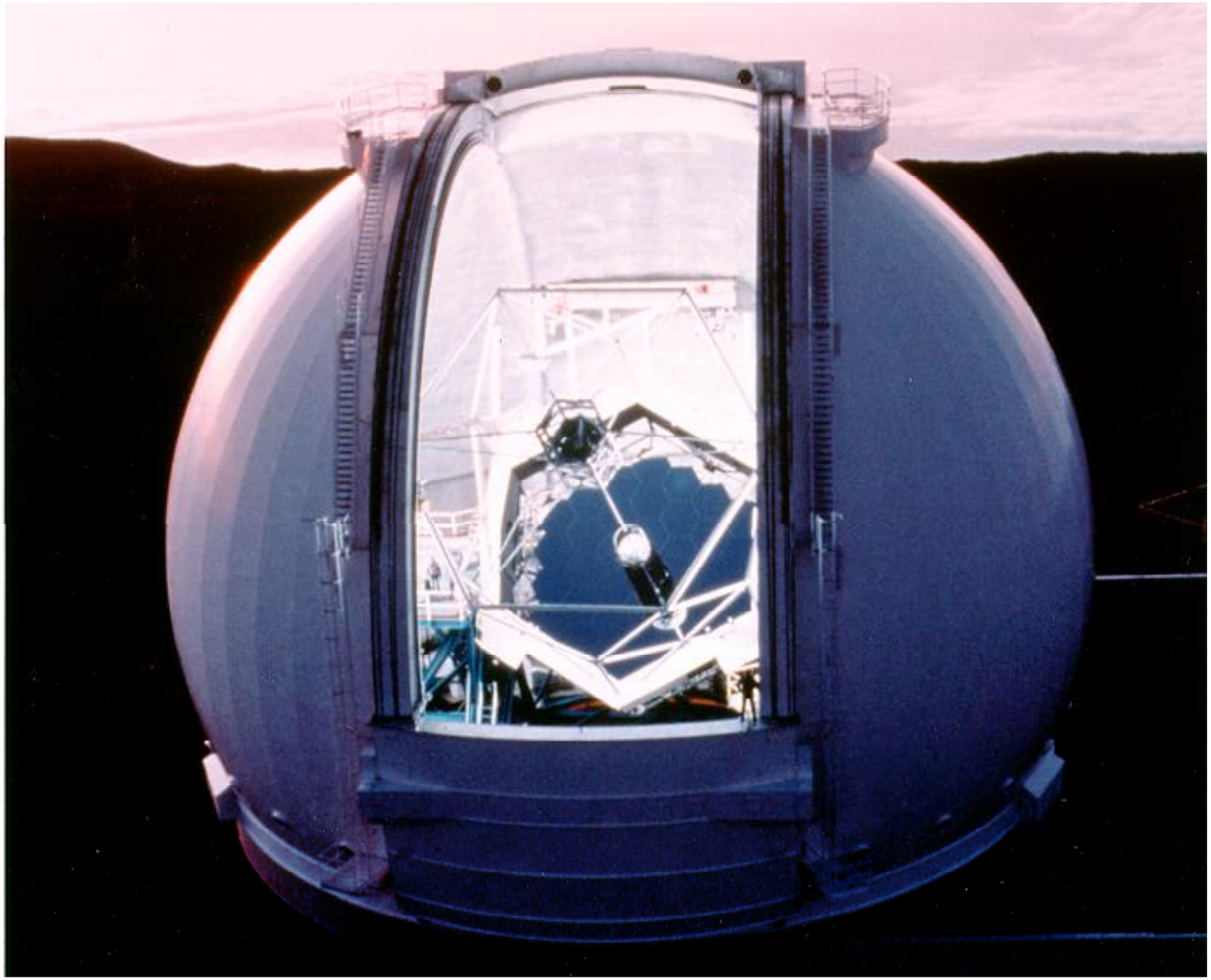

Cal Poly Talk
(reder@jpl.nasa.gov)

*Images courtesy of:*
*Warner Bros. Feature Animation, 1999*
*Society of Motion Pictures And Television Engineers*

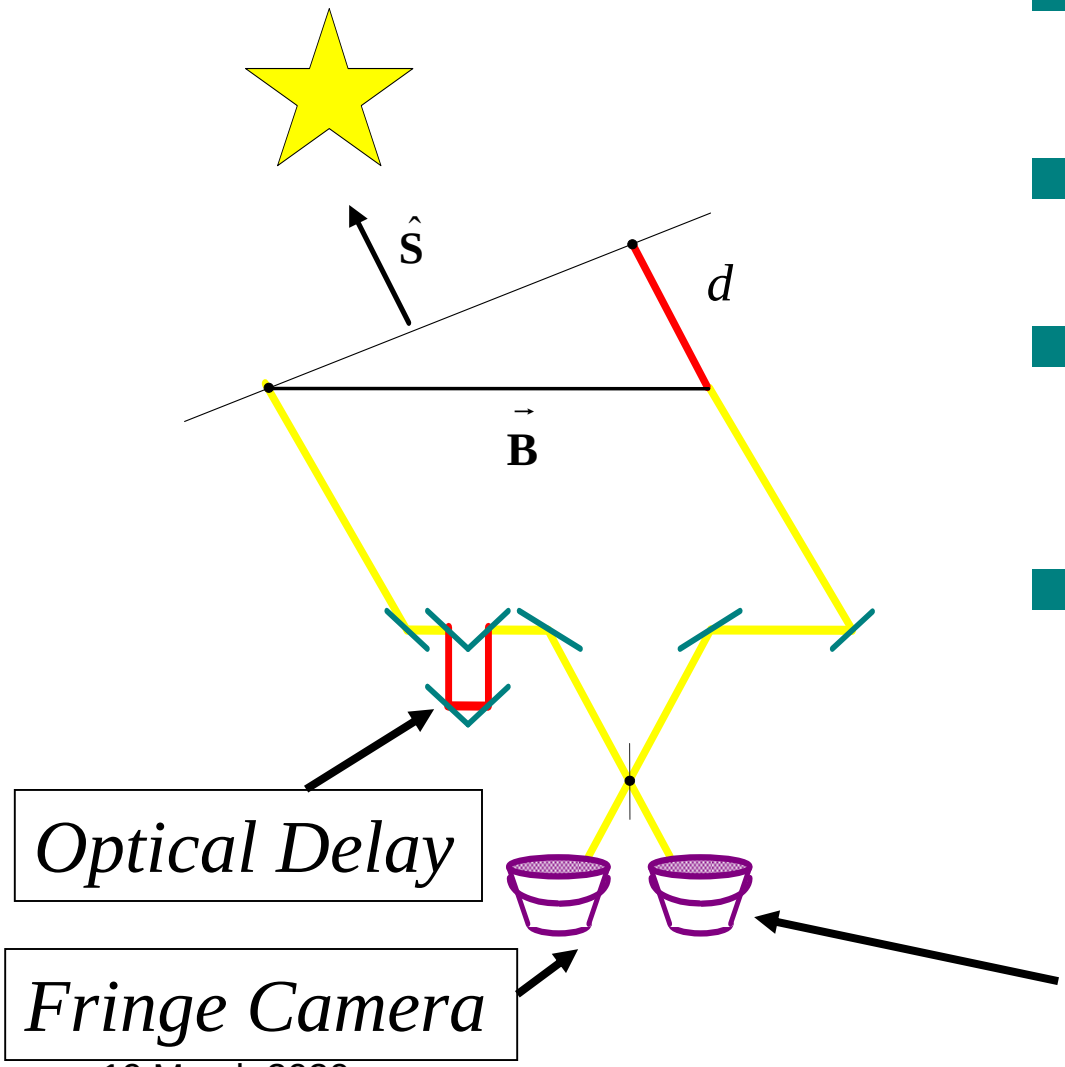
# Keck Interferometer

- Returned to JPL 1999 to join Real-Time Interferometry Software Group to develop the Keck Interferometer.
- Twin Keck Telescopes on Mauna Kea Summit, Hawaii.
- 10m diameter telescopes with full adaptive optics (AO).
- Wavelengths 1.2 um to 10 um (AO operates in visible).
- Science: nulling, differential phase, astrometry, imaging.
  - Goal: detection of Jupiter sized exoplants
- First fringes with Keck Telescopes March, 2001.

# Inside the Dome

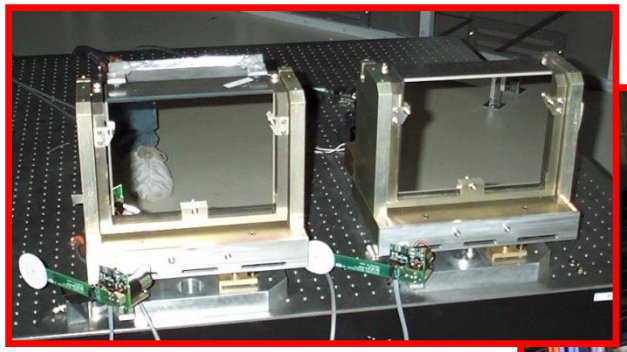


# Astrometry (Measured Position) with a Michelson Inteferometer

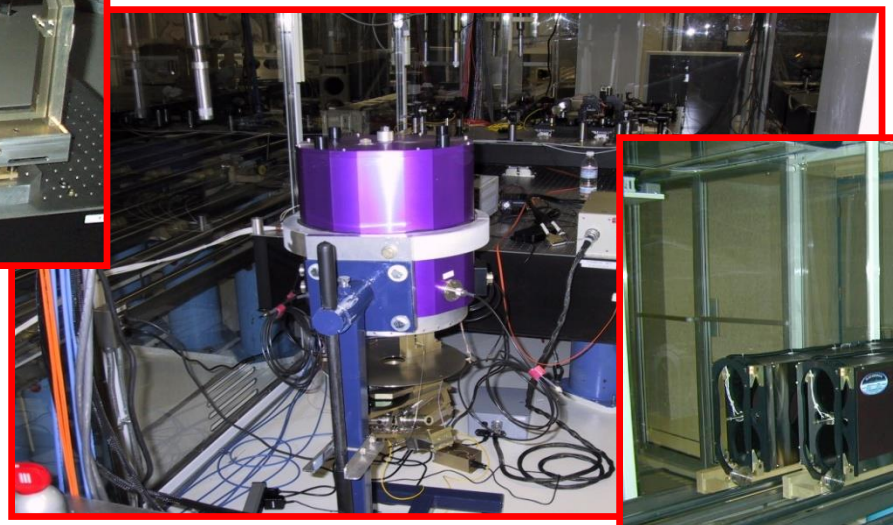



- **For perfect interference, we must have $d = \hat{\mathbf{S}} \cdot \vec{\mathbf{B}}$.**
- **If we know $\hat{\mathbf{S}}$ and $\vec{\mathbf{B}}$, we know what to set *d* to.**
- **Conversely, if we know $\vec{\mathbf{B}}$ and measure *d*, we can learn something about $\hat{\mathbf{S}}$.**
- **If we do this for 3 different values of $\vec{\mathbf{B}}$, we can completely determine $\hat{\mathbf{S}}$.**

# Interferometer Major Components



Beam Transport Optics
(Coude Train)



Fringe Tracker (FATCAT)

Fast Delay Lines (FDL)

Angle Tracker (KAT)

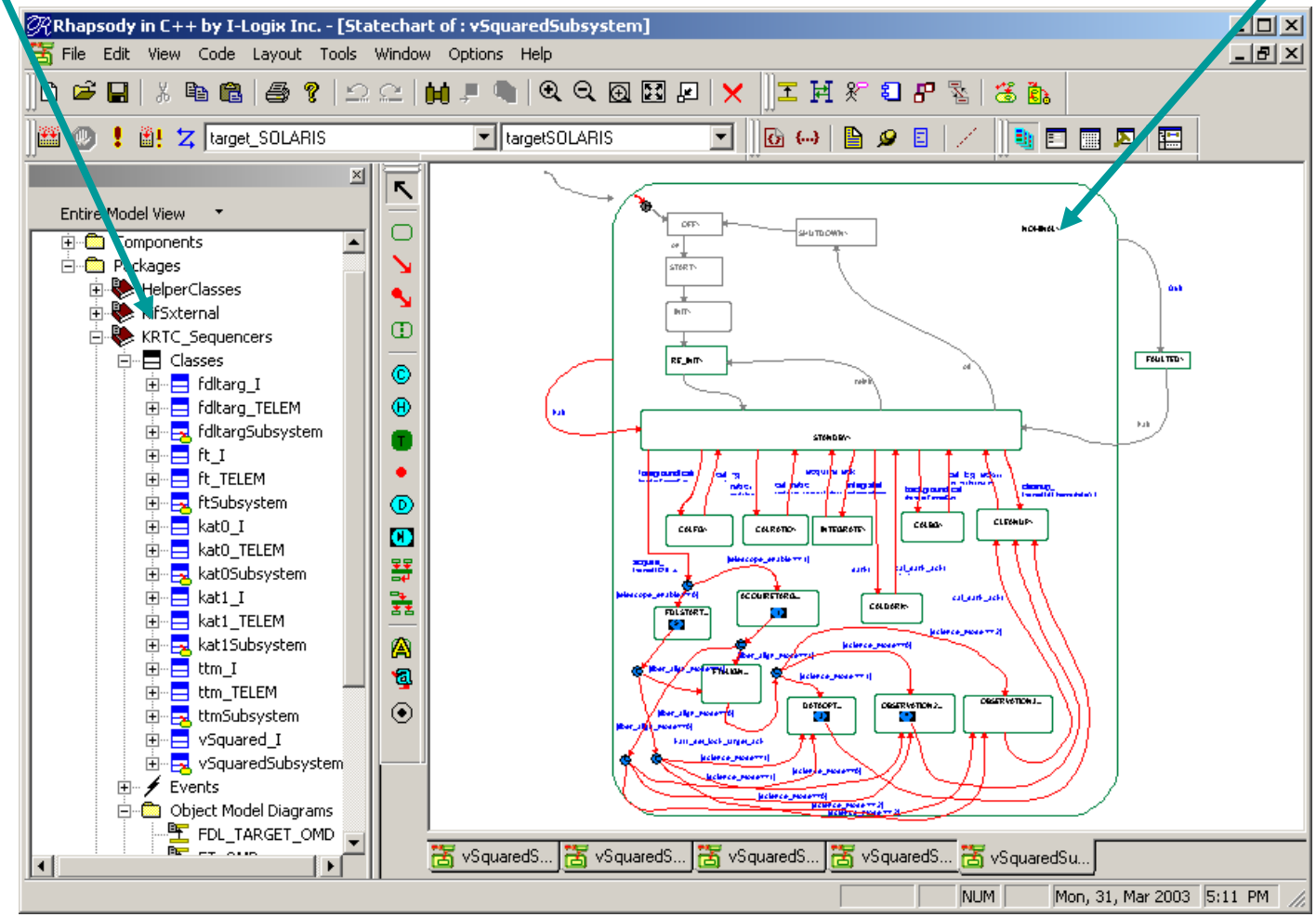
Long Delay Lines (LDL)

Cal Poly Talk
(reder@jpl.nasa.gov)

# Screenshot showing Rhapsody CASE Tool

**Model View**

**State Machine or Object Model Graphical Views**

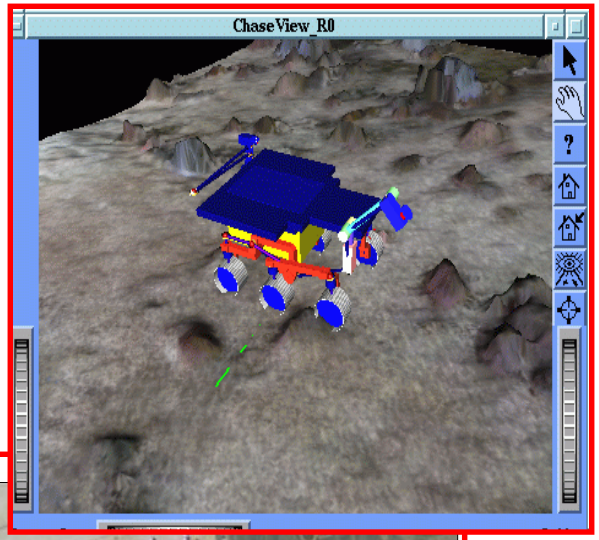


# Smaller Projects

Laser Spectrometer Absorption Instrument Ready for Flight out of Van Nuys Airport

Lake Tahoe Buoy Satellite Sensor Calibration and Validation

Rover Analysis, Modeling, and Simulation

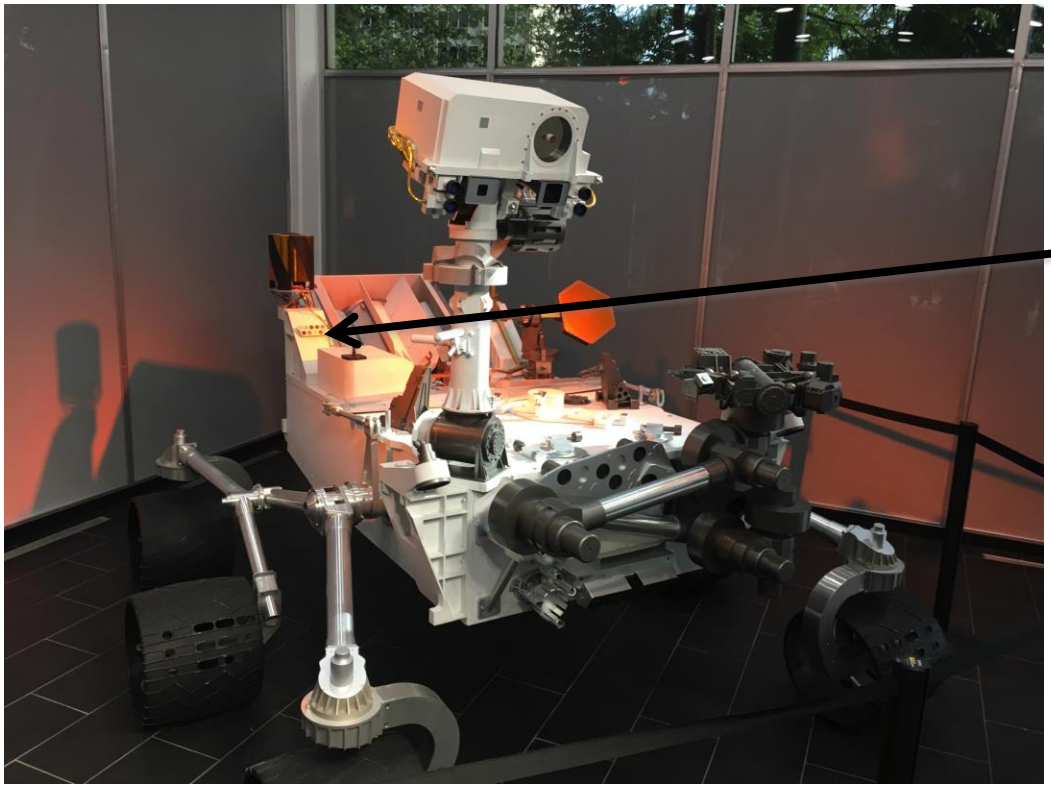


Target Detections Algorithms

Cal Poly Talk
(reder@jpl.nasa.gov)

# Mars Science Laboratory Model

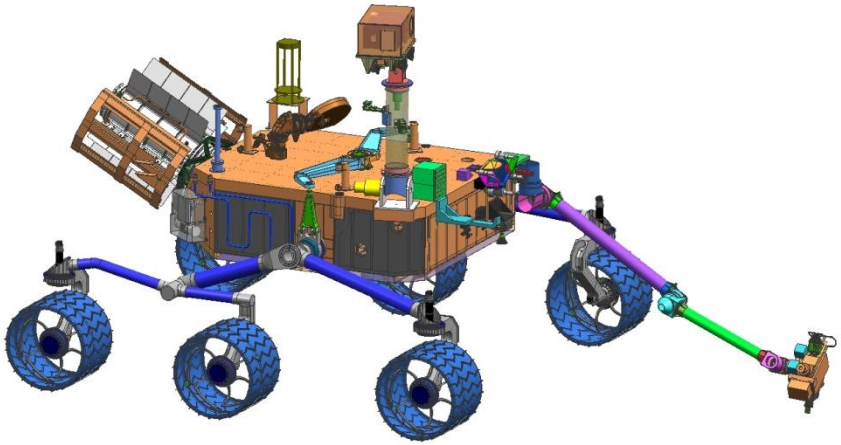
- Joined the Mars Science Laboratory project in 2006
- Transferred to the Flight Software Section in 2007
  - To Lead FSW Flight/Ground Interface Automation Effort



What is this???

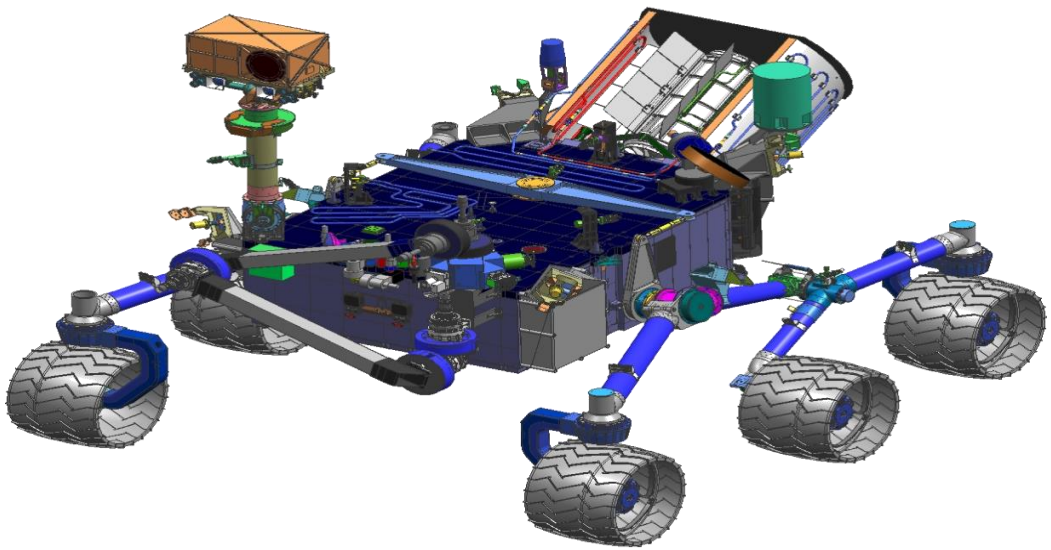
# MSL Project Overview

<u>Science</u>
Focus on Past & Present Habitability of Mars
Highly Capable Analytical Laboratory
Next Generation Remote Sensing & Contact Investigations
Suite of Environmental Monitoring Instruments



<u>Technical Capabilities</u>
One Mars Year surface operational lifetime (669 sols/687 days)
Discovery Responsive over wide range of latitudes and altitudes
Precision Landing via Guided Entry
Skycrane Propulsive Landing
Long Distance Traverse Capability (20 km)
Flexible & Robust Sample Acquisition & Processing

# MSL Automatic Code Generation

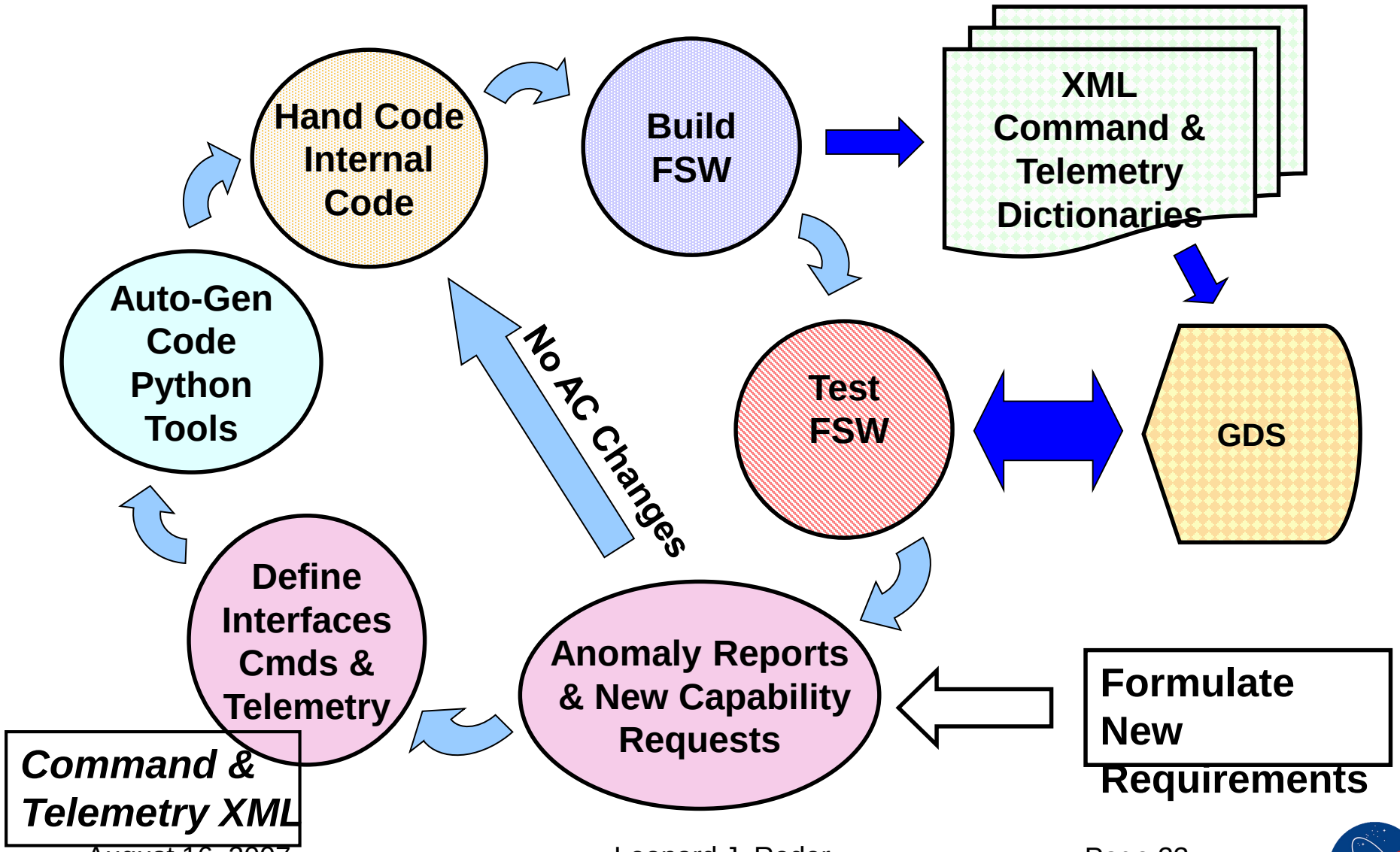


**Embbed System**

- VxWorks/C Impl
- Multi-threaded
- Module to module message based

- Provide formal interface specifications (XML)
- Python tools generate tested and well understood patterns
- Rapidly implement new framework code via automation
- Use of design patterns to enhance maintainability
  - Visitor pattern allows adding new output products
  - Template language “Cheetah” allows rapid prototyping
- Based on MER legacy

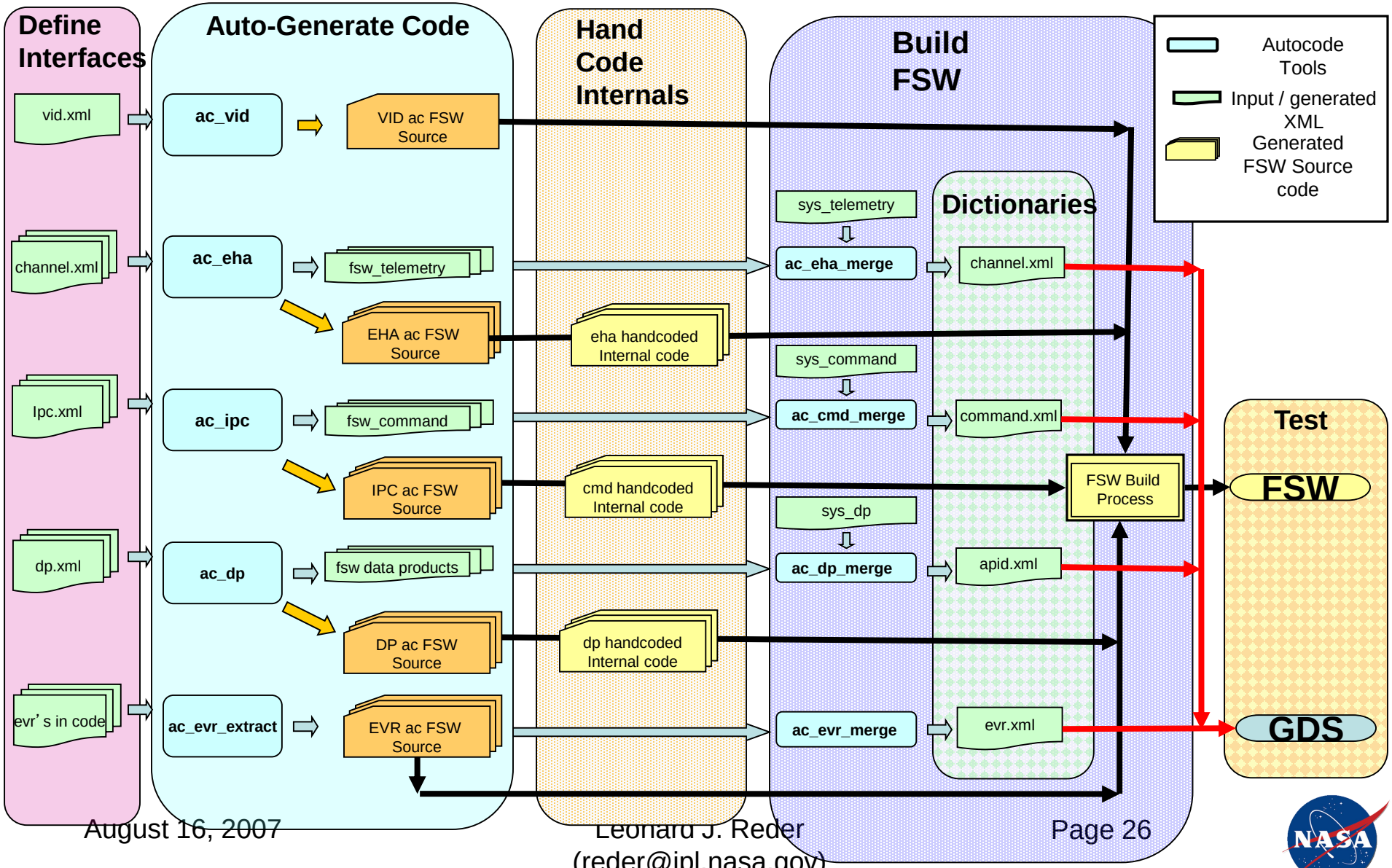
# Auto-Code Generation Process



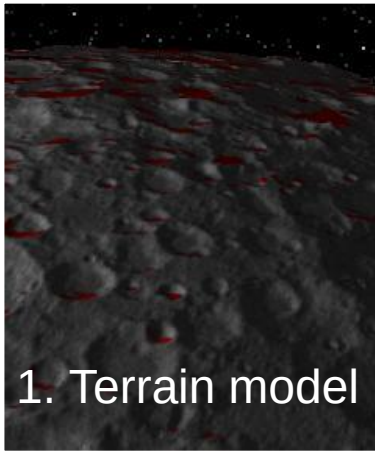


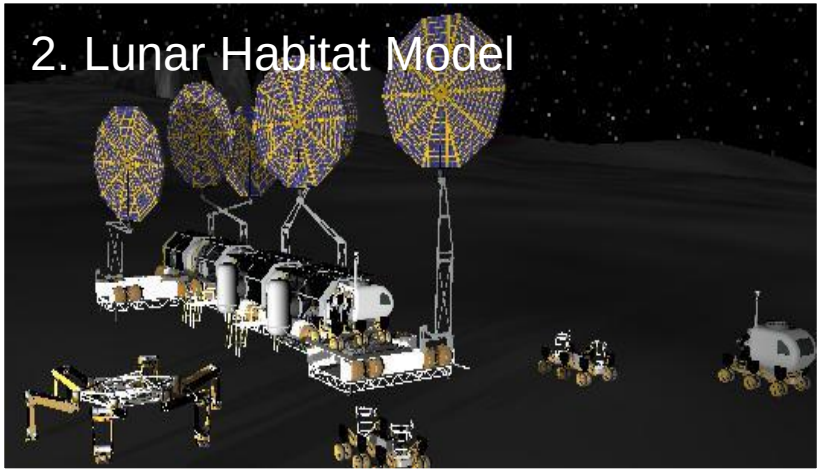

Leonard J. Reder
(reder@jpl.nasa.gov)

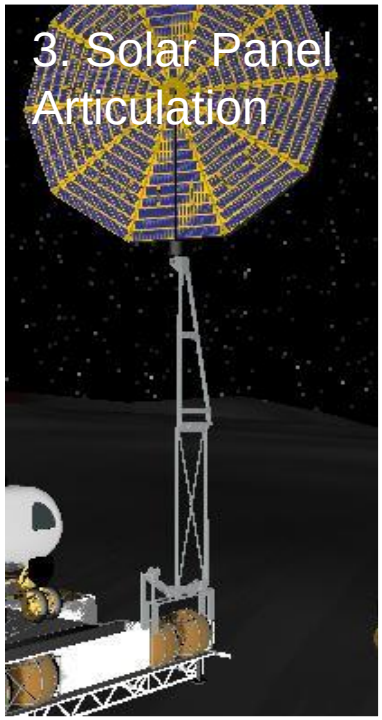
# Auto-Code Flow Overview

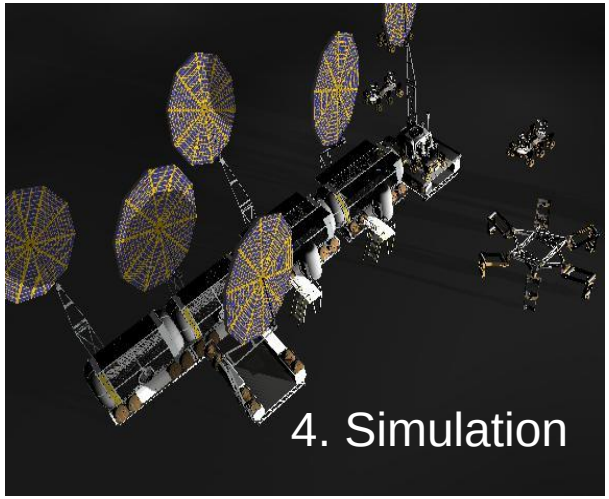


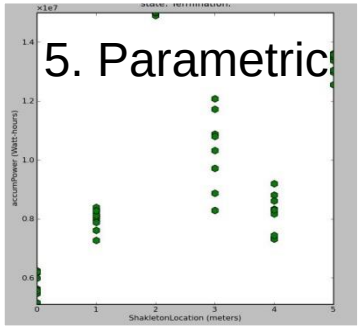
# Lunar Surface Operations Simulation

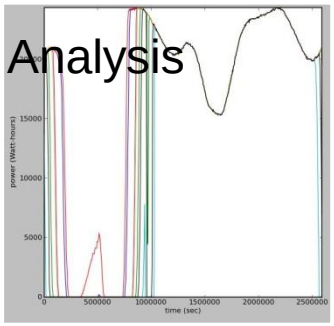


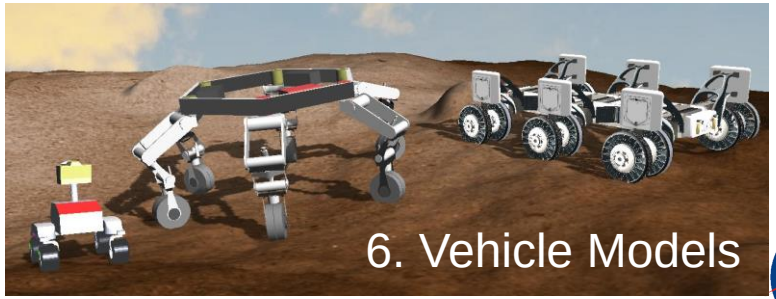



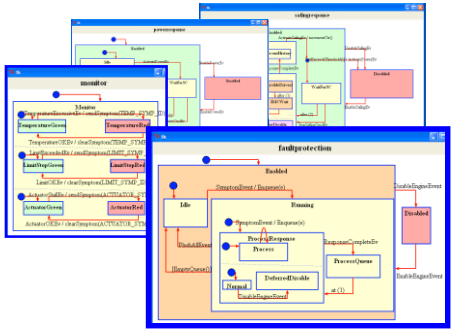



# Verifiable Requirements Process

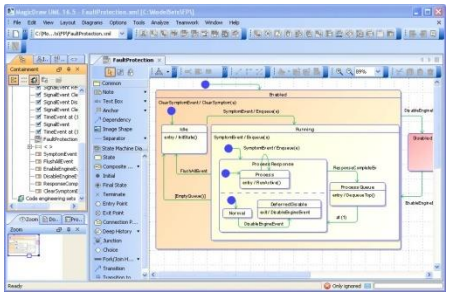
Requirements

python™



Python Simulation of StateCharts

Flight Software Development



MagicDraw Statechart Models

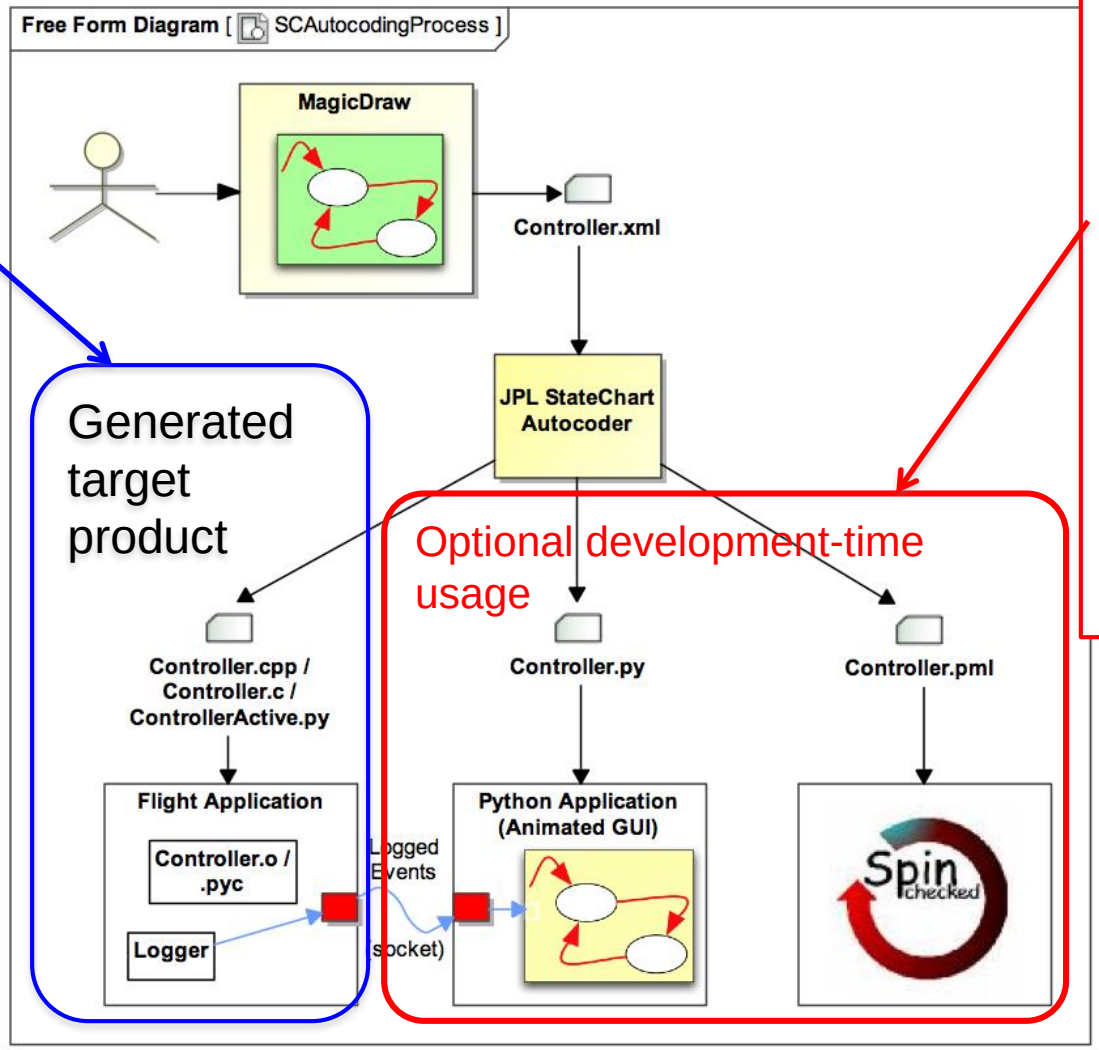
- Python Executable Statechart Capability
  - ❑ Immediately simulate of behaviors
  - ❑ Use common models between Systems and Flight Software Engineers
  - ❑ State transition trace GUI produced from model
  - ❑ Small percentage of manual coding
  - ❑ Ability to run the model stand-alone

# StateChart autocoding process

Generated options:

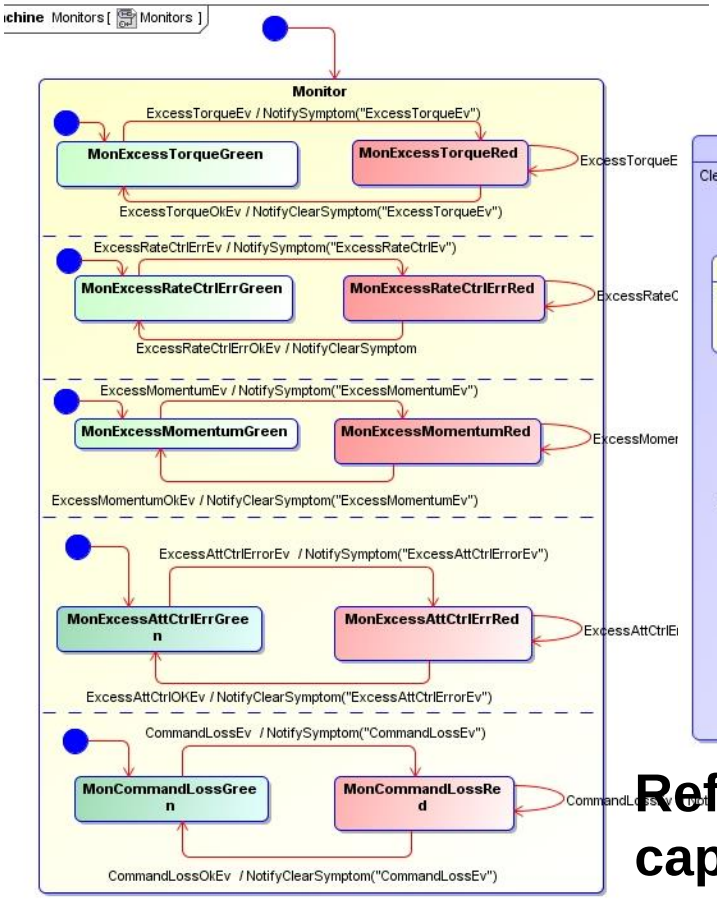
1.C/C++ Builds for Linux, vxWorks, Mac OSX

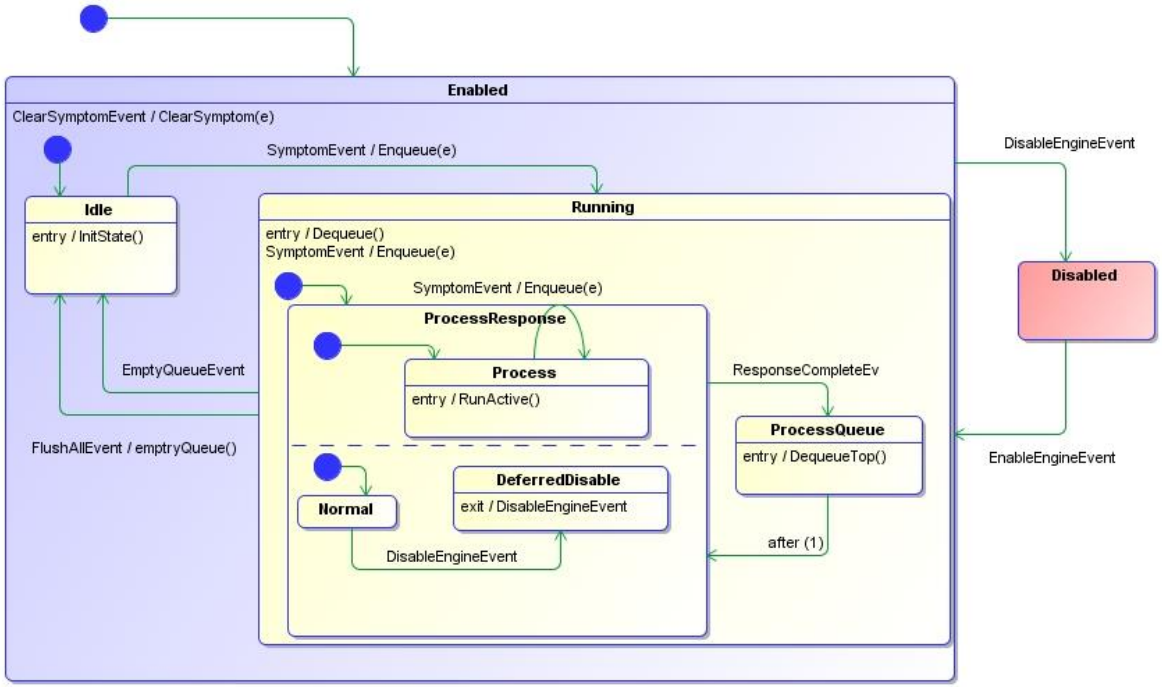
2.Python executable on Mac, Linux, Windows




- Python trace GUI widget works with any target language.
- Promela generation for Spin model checking

# FP Sim Run: Command Loss Demo



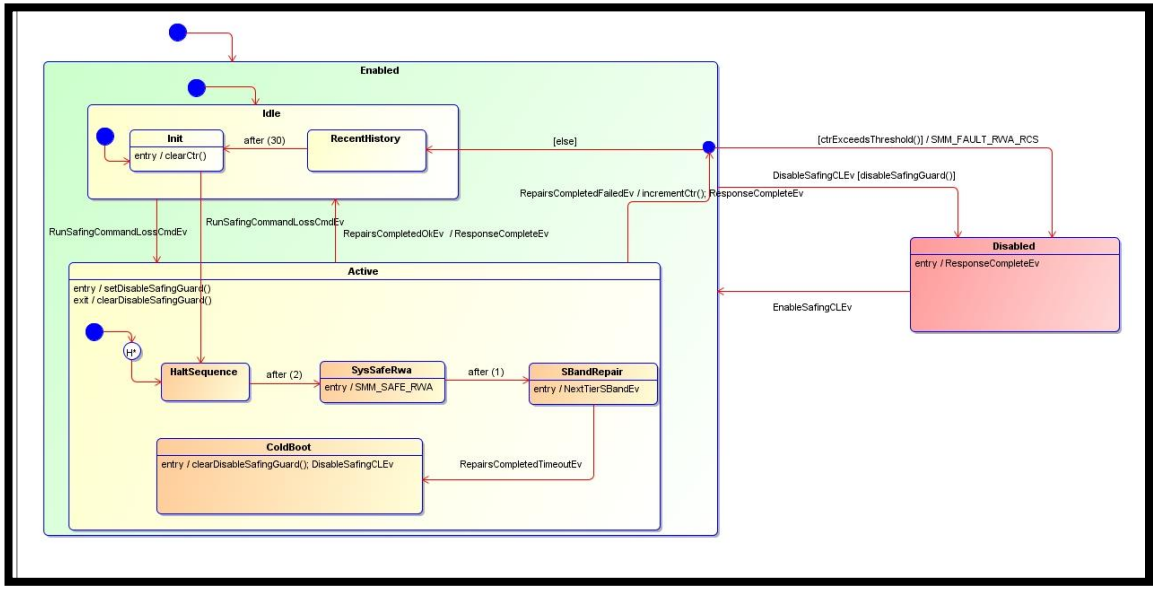




**5 emulated monitors, each with red/green states**

**Reference Fault Protection Engine: main capabilities are all implemented**

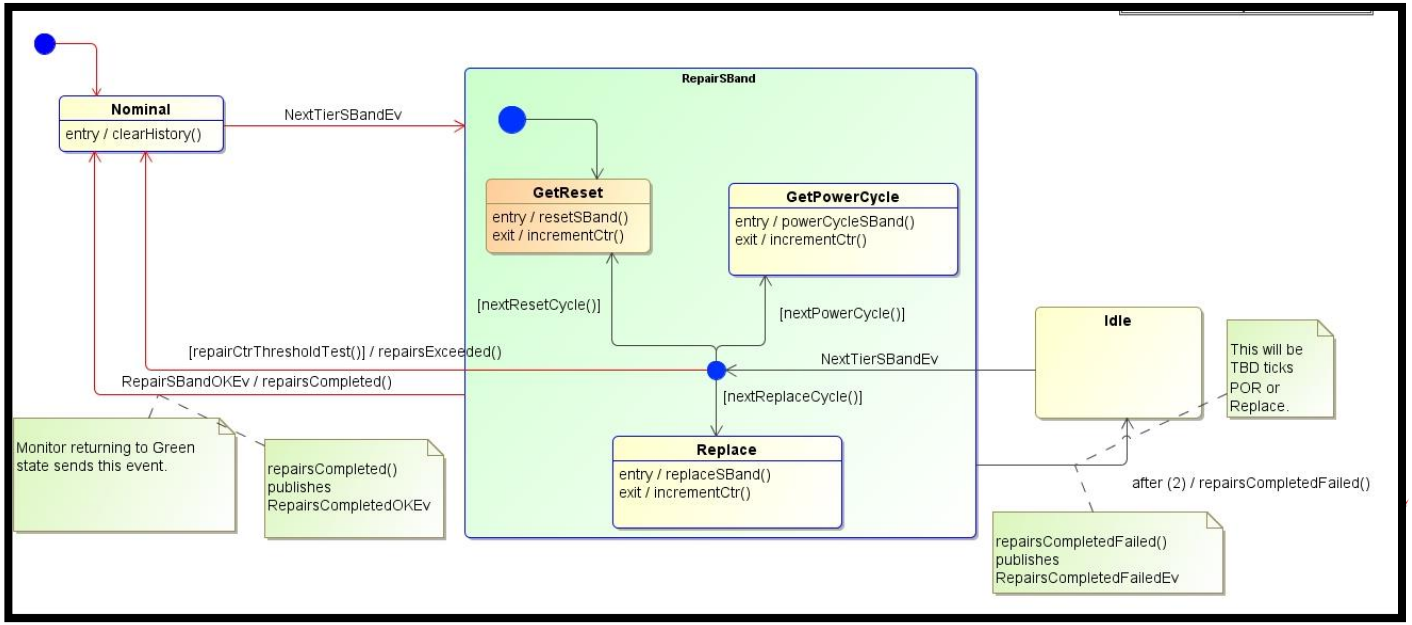
- *Queues, monitor to response mapping, checking for active monitors, etc*
- *Deep Impact, DS-1 Philosophy, et. Al. Wagstaff/Watney 2006 R&D Demo – updated per SMAP requirements*

# FP Sim Run: Command Loss Demo

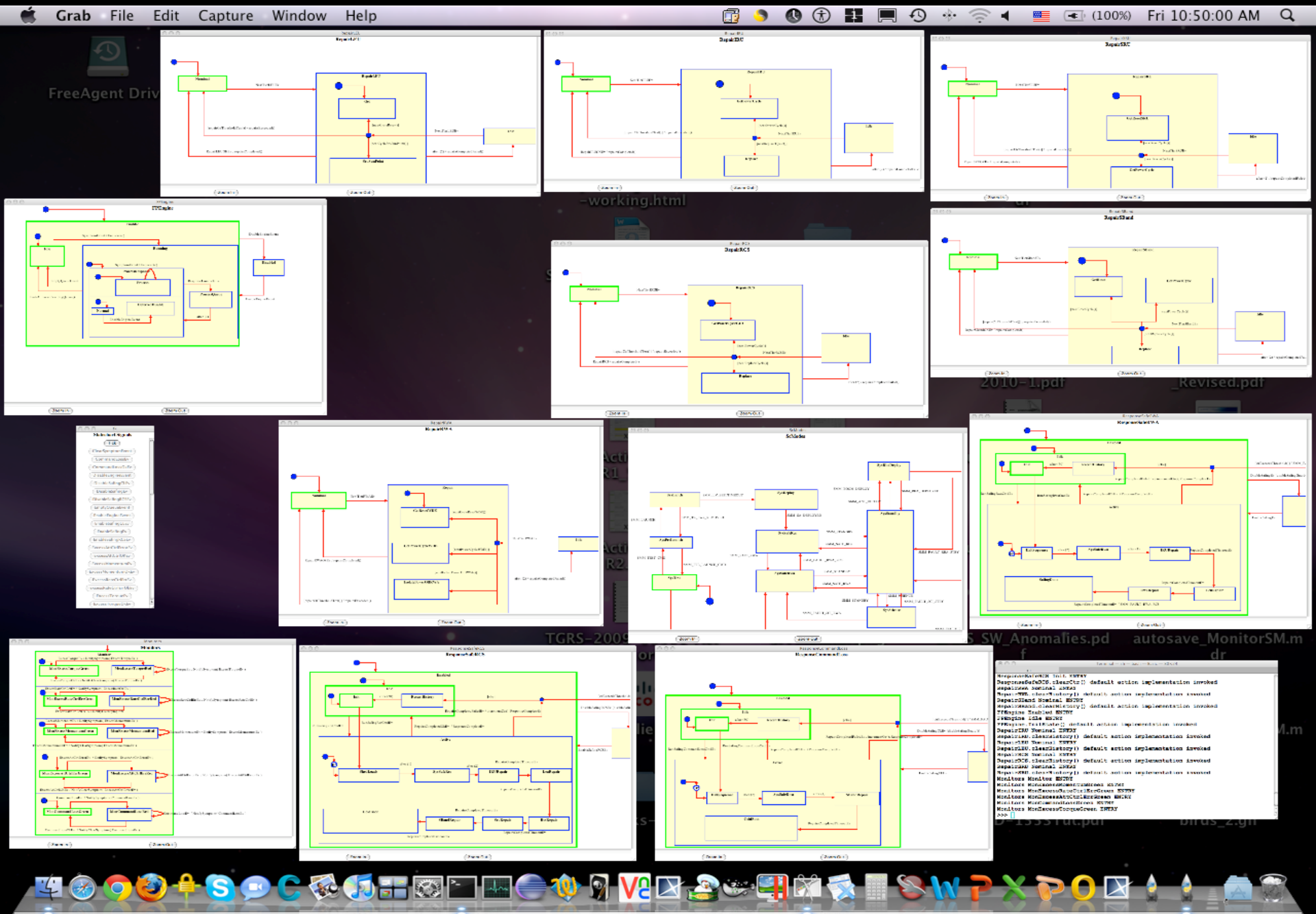



Command Loss System FP Response: Preliminary tiers demonstrate general flow of execution

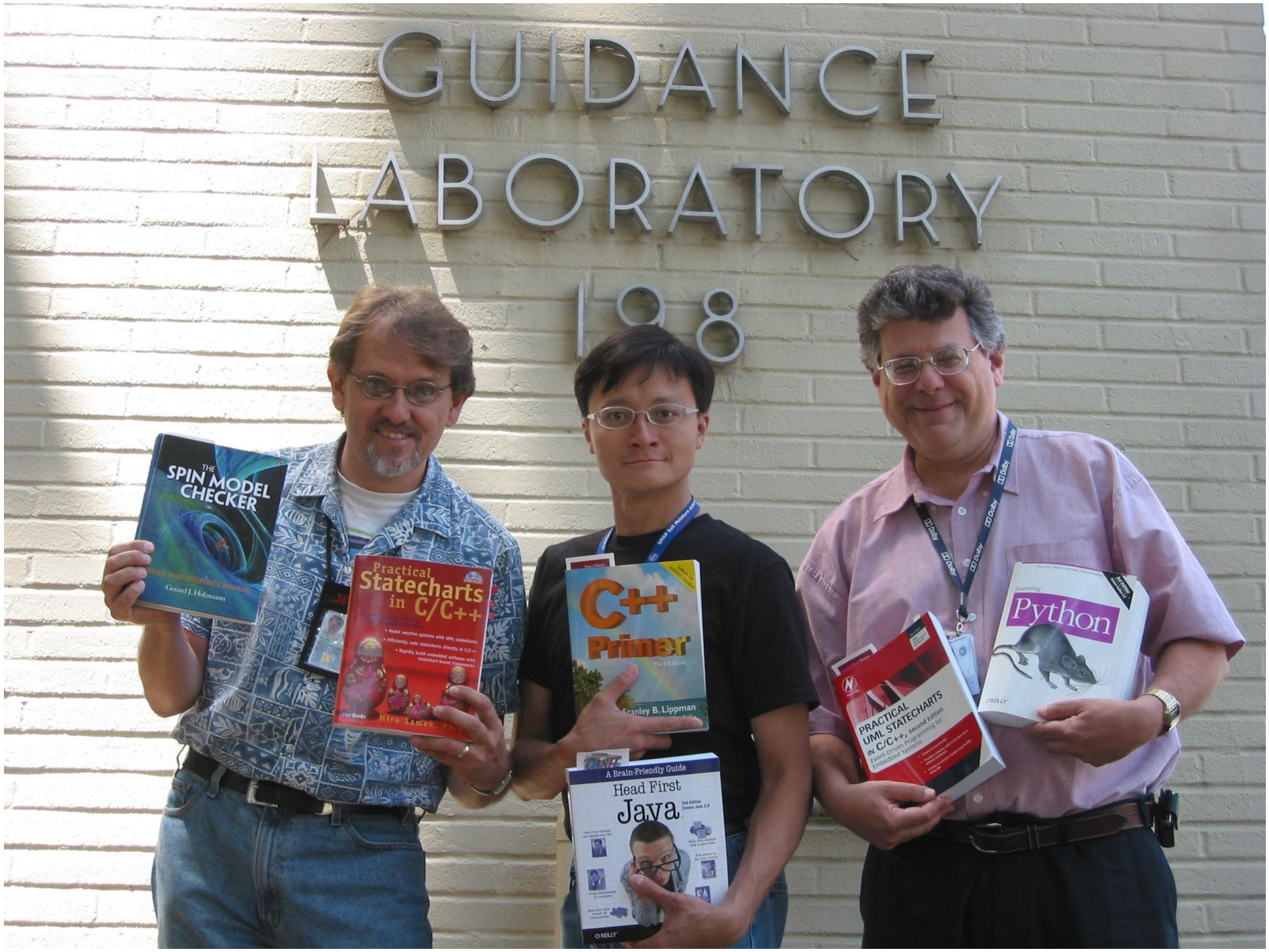
S-Band Repair Manager: Repair tiers demonstrated



# System FP Executable Functional Simulation



# Technology & Team

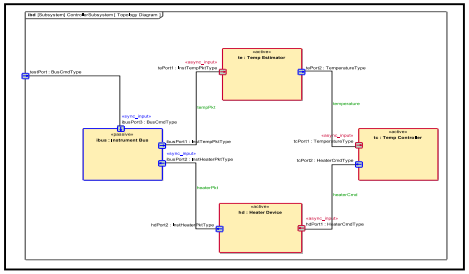


# Modeling for Partitioned and Multi-core Flight Software Systems JPL R&TD Task (Instrument Software Framework)

- Objective
  - Develop modeling methodologies and framework to demonstrate that a single modeling artifact can be used for both analysis and rapid deployment of software components on a partitioned or multi-core computing platforms.
- Significance
  - Provides flexibility and efficiency in fielding systems that will result in an order of magnitude savings in labor over the current state of the art of flight software development at JPL.
- Over the past 2 years the task has:
  - Evaluated AADL for analysis and code generation
  - Adopted and refined a C++ Component Instrument Software Framework (ISF)
  - Developed Domain Specific Syntax XML specification of C++ code
  - Developed YACGEN (Yet Another Code Generator) to generate ISF C++ Topologies, Components and Ports

# Component Autocoder Products

***Application Component Model***



MagicDraw Component Plugin

***Domain Specific XML Files***

Component AI.xml

Port AI.xml

SerializedData AI.xml

Topology AI.xml

ISF AutoCoder (Python)

Component.cpp

Port.cpp

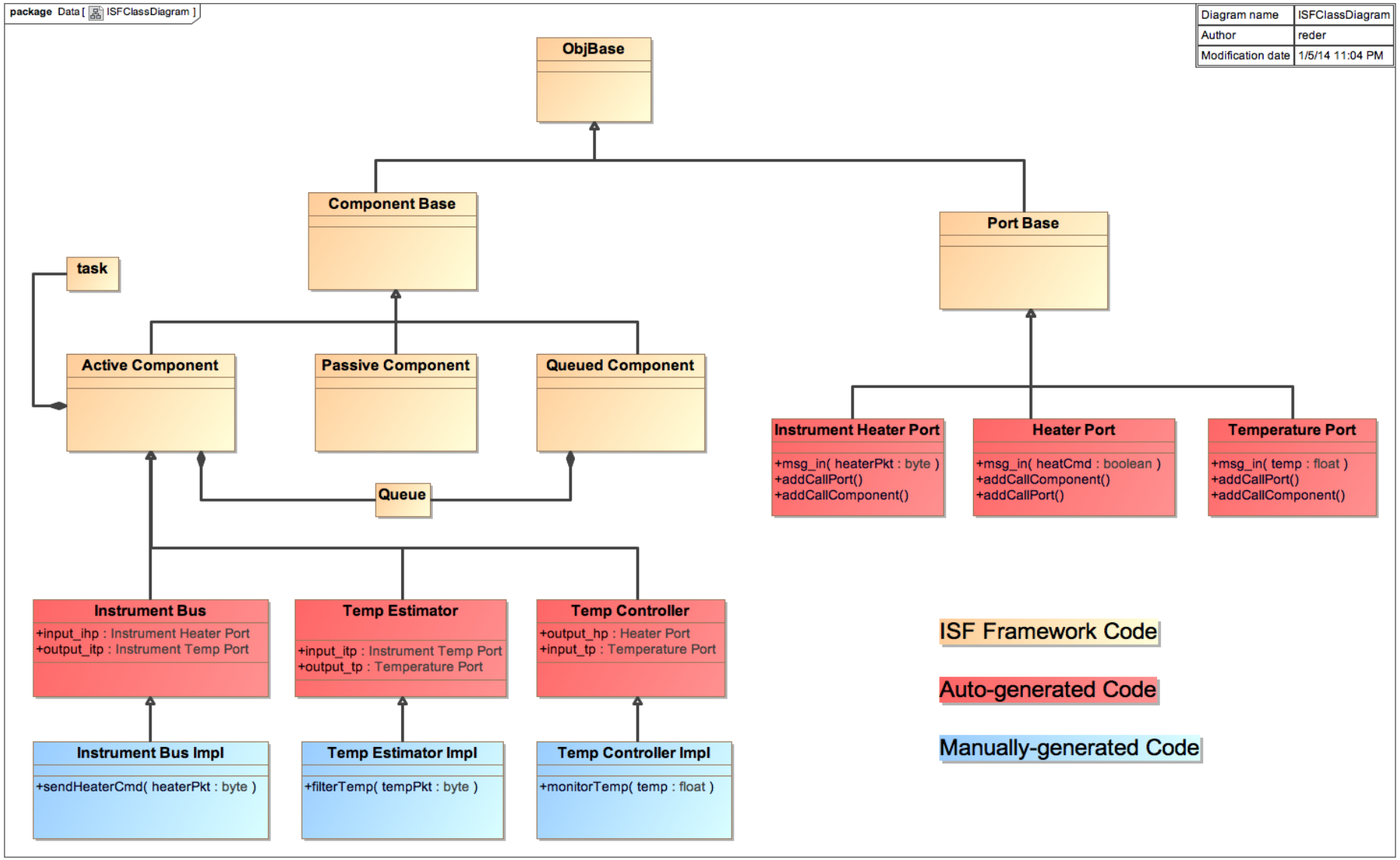
SerializedData.cpp

Topology.cpp

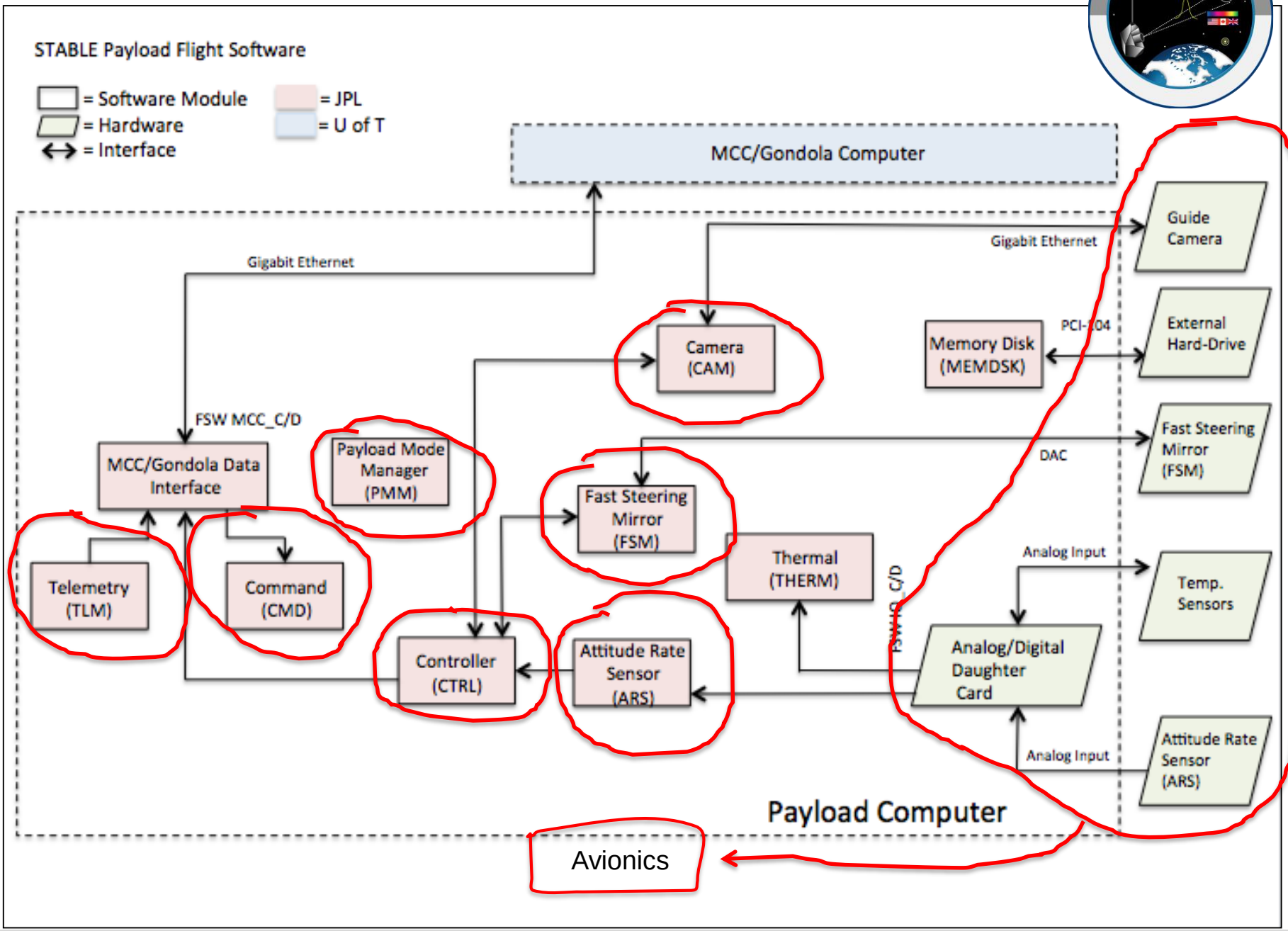
***Application Flight Code***

***Application Interface Specification***

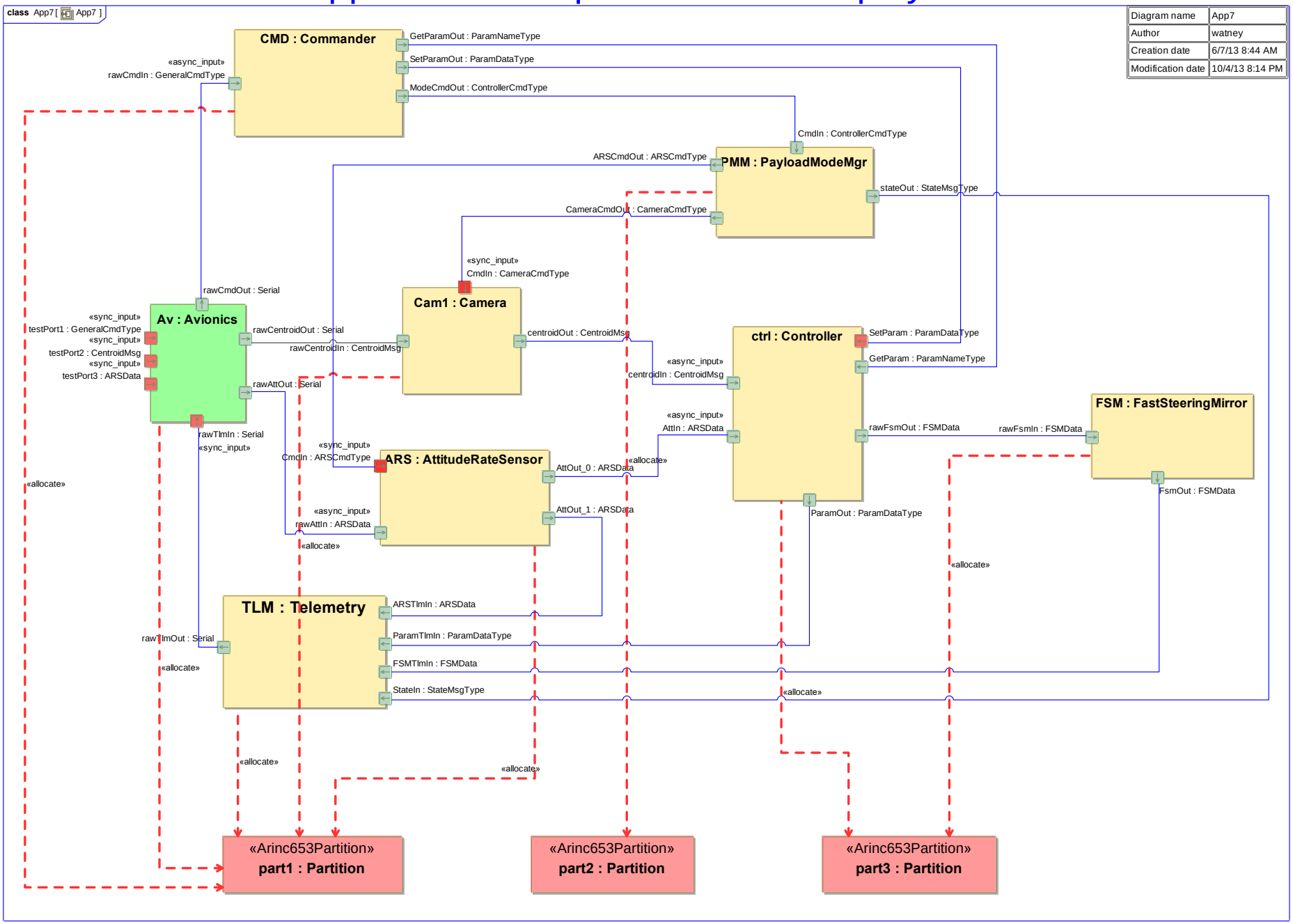
# Example ISF Application Class Diagram



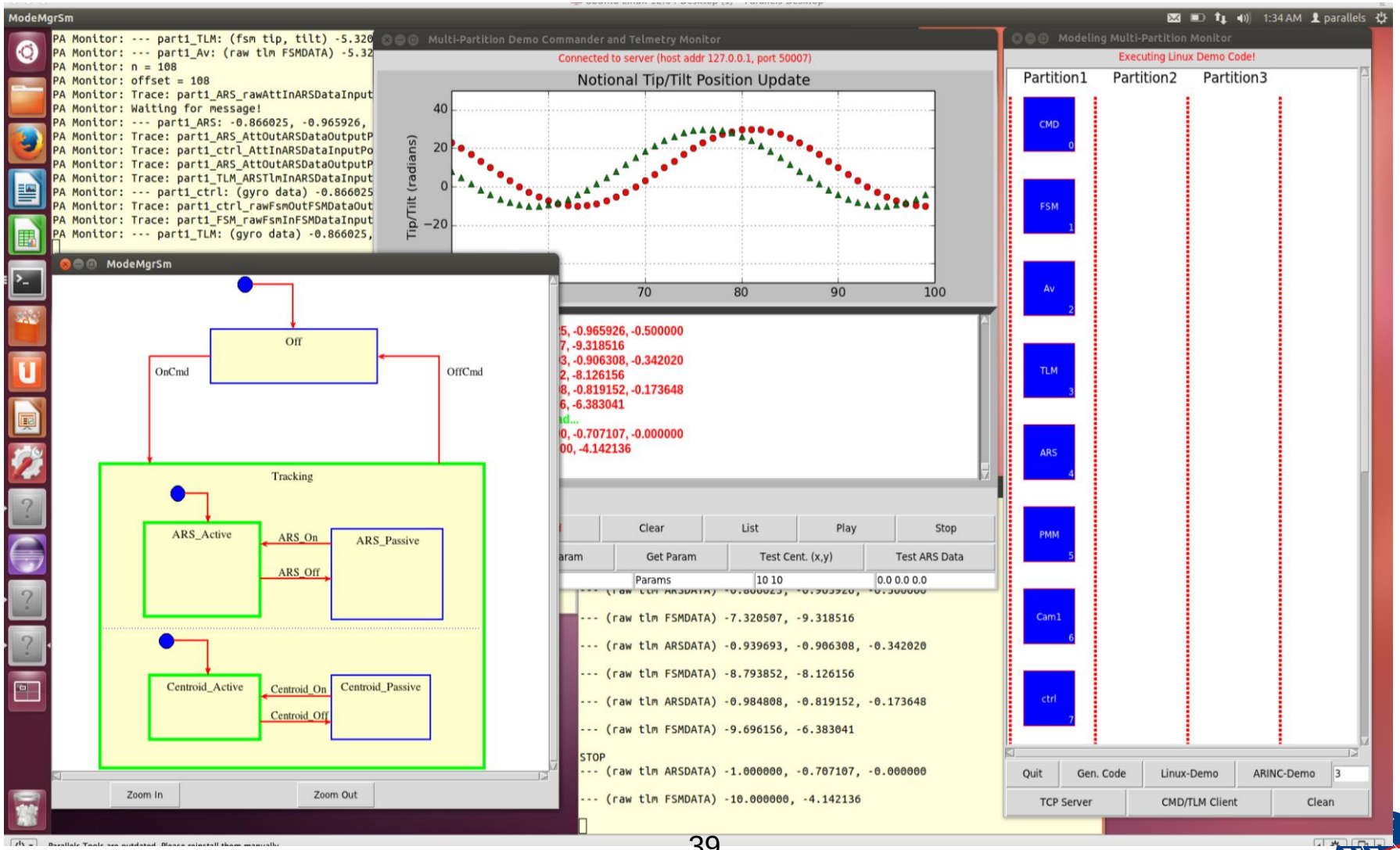
# STABLE Instrument PDR



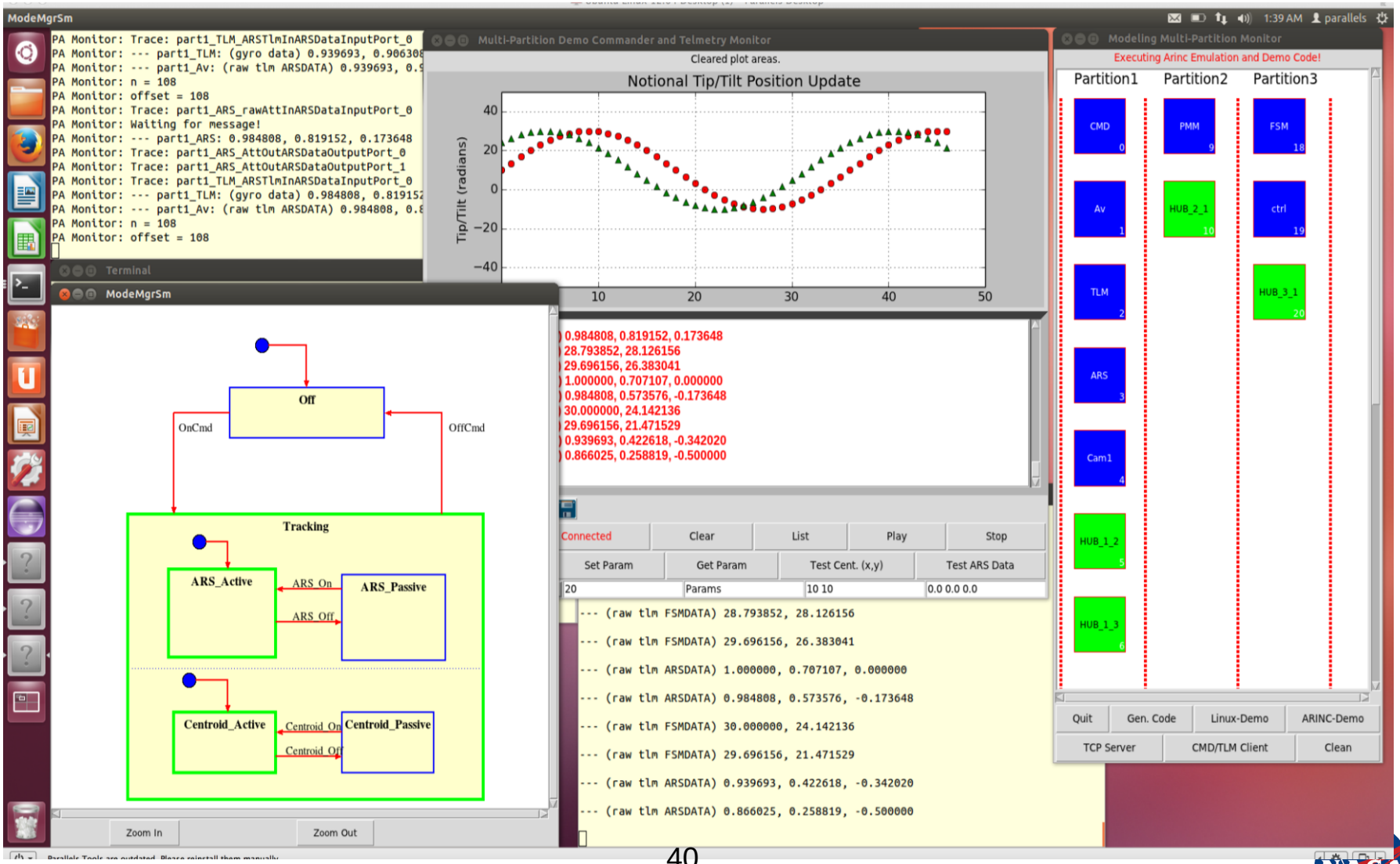
# Application Component Model Deployments



# Stable Demo Linux (single process/partition) Deployment



# Stable Demo ARINC653 Emulation (three partition) Deployment



# Small Scale FSW Group Projects

All these projects using ISF (now called fprime) and component modeling within JPL'S new avionics

•ISF and modeling tools soon to be open sourced

•JPL Statechart Autocoder available at https://github.com/JPLOpenSource/SCA

- Map the lunar south pole
- Will be first cubesat to reach the moon
- Near infrared laser
- On-board spectrometer measure surface composition

- Near-Earth Asteroid Scout
- Perform mapping of an asteroid
- Solar sail propulsion

- Mars Helicopter aka "Leonardo"
- Proposed add-on to Mars 2020 mission
- Scout a head of rover for driving and exploring route
- Current proof-of-concept

# W. M. Keck Observatory: Feb. 2002