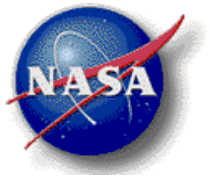

SDR/STRS Flight Experiment and the Role of SDR-Base Communication and Navigation Systems

Richard C. Reinhart & Sandra K. Johnson
Communications Division
NASA's John H. Glenn Research Center
Cleveland, Ohio

IDGA
6th Annual Software Radio Summit
February 25 - 28, 2008

This presentation describes an open architecture SDR (software defined radio) infrastructure, suitable space-based radios and operations, entitled Space Telecommunications Radio System (STRS). SDR technologies will endow space and planetary exploration systems with dramatically increased capabilit reduced power consumption, and less mass than conventional systems, at costs reduced by vigorous competition, hardware commonality, dense integration, minimizing the impact of parts obsolescence, improved interoperability, and software re-use. To advance the SDR architecture technology and demonstrate its applicability in space, NASA is developing a space experiment of multiple SDRs each various waveforms to communicate with NASA's TDRSS satellite and ground networks, and the GPS constellation. An experiments program will investigate S-band and Ka-band communications, navigat and networking technologies and operations.

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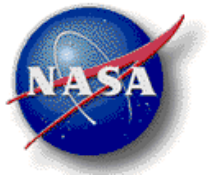

SDR/STRS Flight Experiment and the Role of SDR-Based Communication and Navigation Systems

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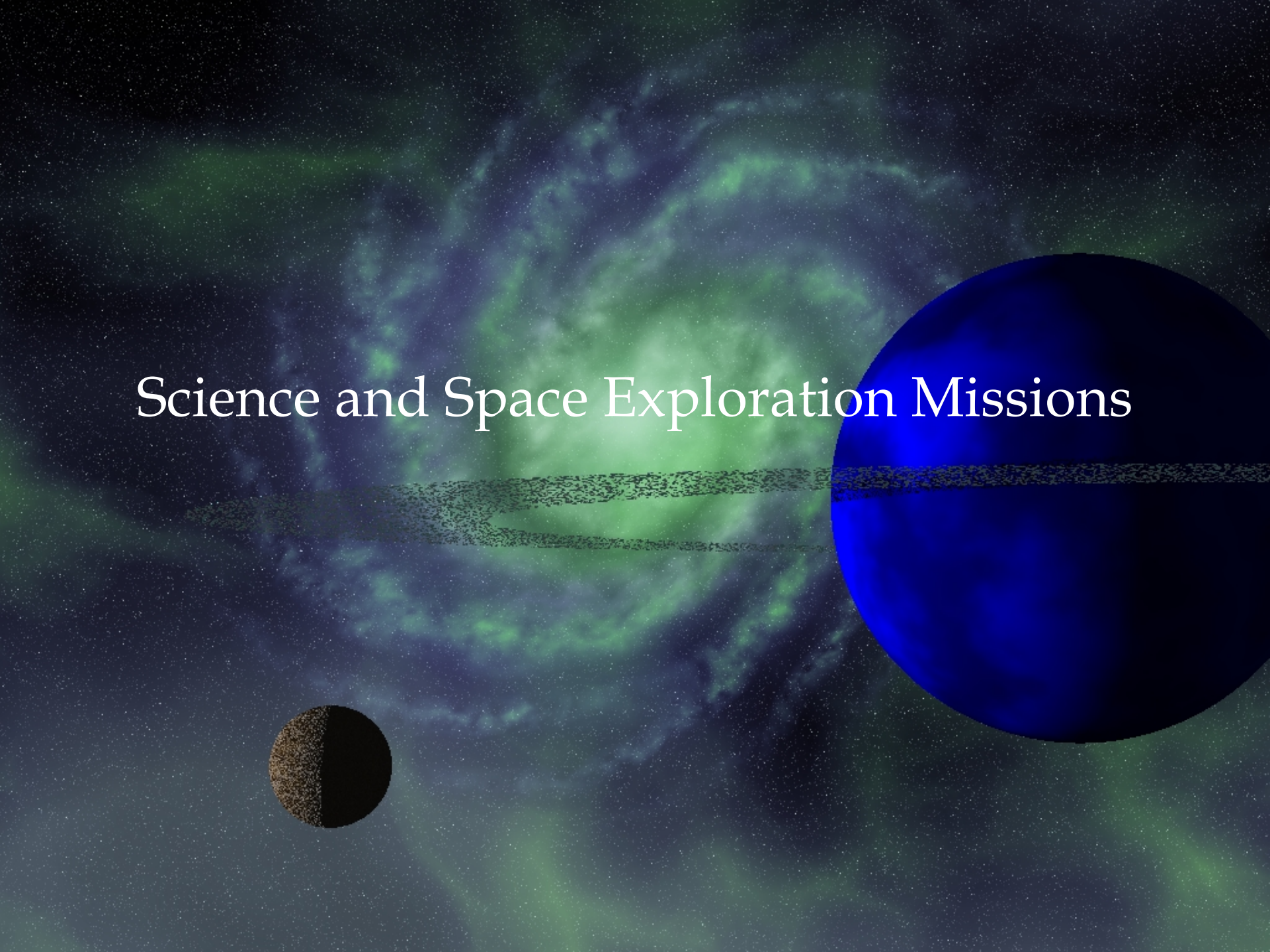
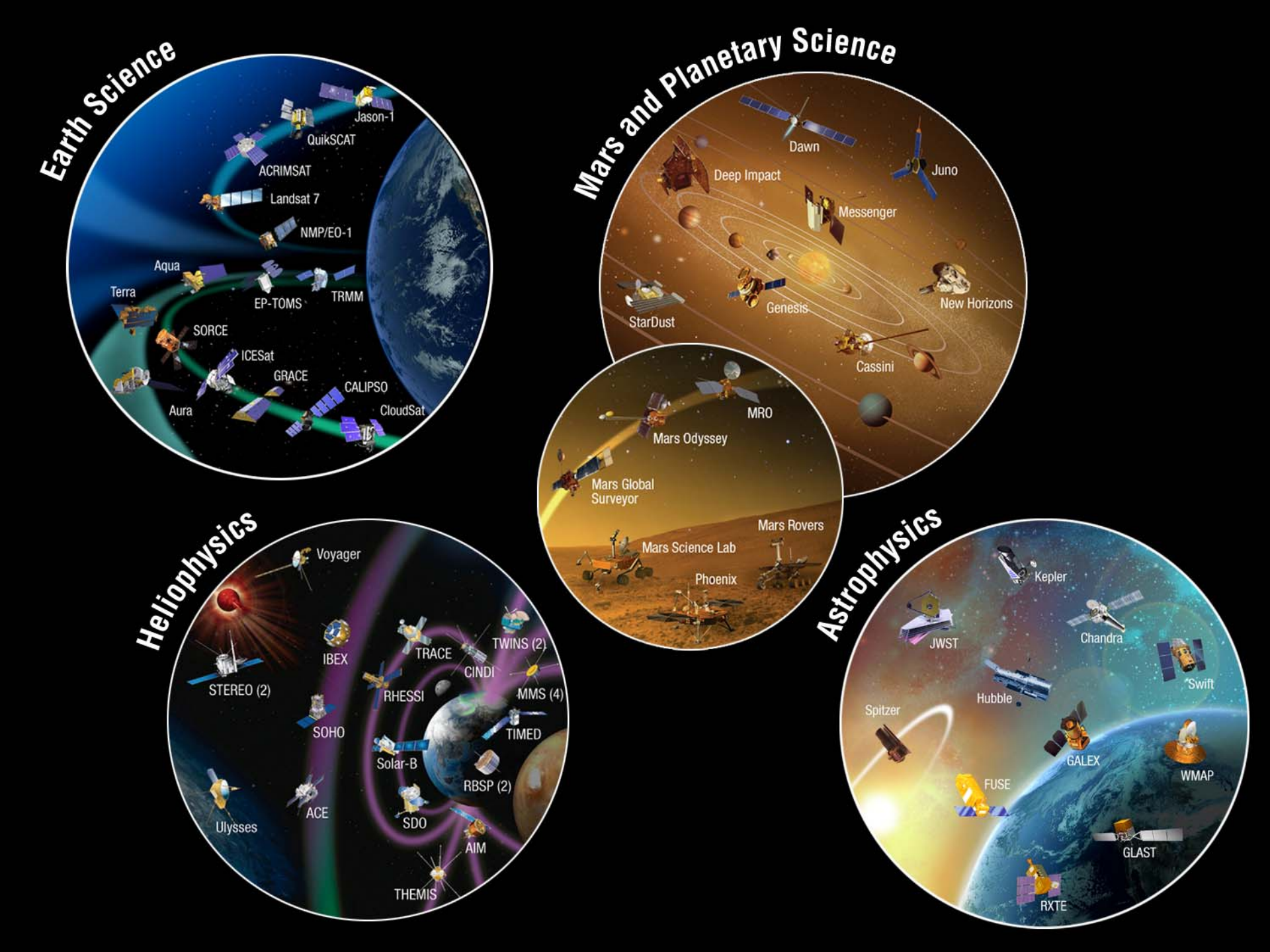
Briefing Content

- NASA's Science and Space Exploration Missions
  - What are the drivers and constraints for space SDR?
- SDR & NASA's SDR Standard Open Architecture: The Space Telecommunications Radio System (STRS) Standard
- SDR/STRS-based Communication, Navigation, and Networking reConfigurable Testbed, (CONNECT) , experiment aboard ISS

Science and Space Exploration Missions




Earth Science
Jason-1
QuikSCAT
ACRIMSAT
Landsat 7
NMP/EO-1
Aqua
Terra
EP-TOMS
TRMM
SORCE
ICESat
GRACE
CALIPSO
Aura
CloudSat
Mars and Planetary Science
Dawn
Deep Impact
Juno
Messenger
Genesis
New Horizons
StarDust
Cassini
MRO
Mars Odyssey
Mars Global Surveyor
Mars Rovers
Mars Science Lab
Phoenix
Heliophysics
Voyager
IBEX
TRACE
TWINS (2)
CINDI
STEREO (2)
RHESSI
MMS (4)
SOHO
TIMED
Solar-B
RBSP (2)
ACE
Ulysses
SDO
AIM
THEMIS
Astrophysics
Kepler
JWST
Chandra
Swift
Hubble
Spitzer
GALEX
WMAP
FUSE
GLAST
RXTE

Exploration Roadmap

05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

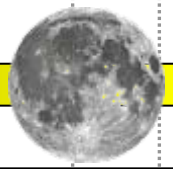
CEV Contract Award

Orion/Ares Operational

Lunar Outpost Buildup

7th Human Lunar Landing

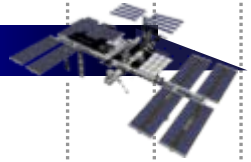
Lunar Robotic Missions



Science Robotic Missions

Mars Expedition Design

Commercial Crew/Cargo for ISS

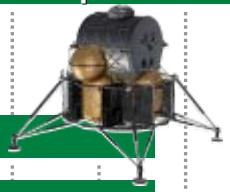


Space Shuttle Operations

Orion CEV Development

ARES I Launch Vehicle Development

Orion Production and Operations



Early Design Activity

Lunar Lander Development

Lunar Heavy Launch Development

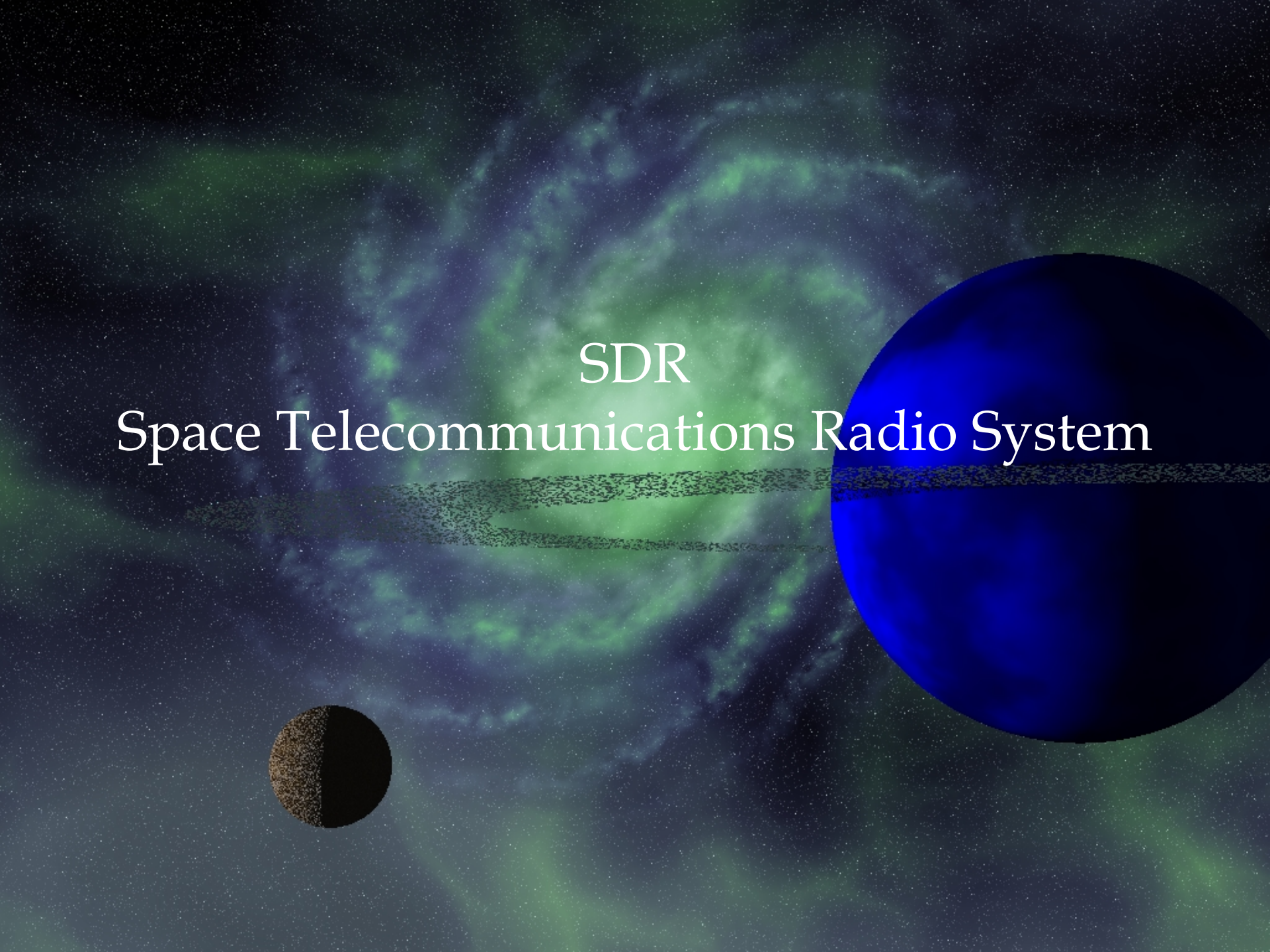
Earth Departure Stage Development

Surface Systems Development

Note: Specific dates and milestones not yet established.

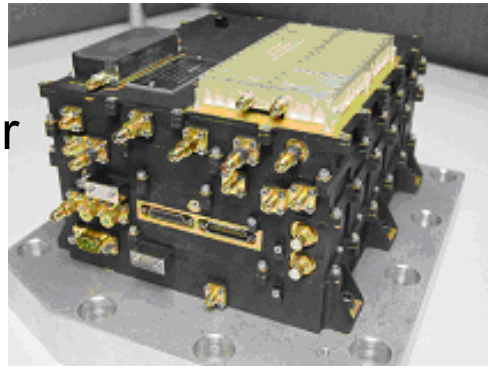
Drivers for NASA Space SDR

- **Radiation Suitable Processing & Memory**
  - Less capable than terrestrial, often lagging by a generation or two.
  - Limits both the footprint and complexity/capability of the infrastructure.
- **Spacecraft Resource Constraints**
  - Spacecraft size, weight, and power limitations on spacecraft.
  - Architecture overhead must be balanced against these spacecraft constraints.
- **Reliability**
  - Designed to prevent single point failures.
  - Crewed missions have high reliability requirements, especially for safety critical applications.
- **Specialized Signal Processing Abstraction**
  - Waveforms to be deployed on specialized hardware (FPGAs, ASICS)
- **Space Waveforms**
  - Data rates range from kbps to Gbps.
  - Frequencies from MHz to GHz


SDR
Space Telecommunications Radio System

SDRs Provide Flexibility Through Software Reconfiguration

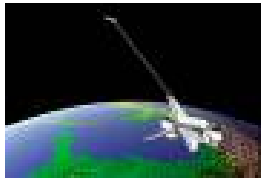
- Reconfigure communication and navigation functions
  - According to mission phase (mass reduction technique)
  - Emerging/changing Requirements
    - Adaptable, Flexible
  - Post-launch software upgrades
- Common hardware platforms for multiple radios over a variety of missions
- Multi-function SDR provides new operational capability
- NASA's early SDR developments
  - JPL's UHF Electra and GPS Blackjack receiver
  - ITT's combined S-band and GPS receiver: Low Power Transceiver (LPT)



JPL's Electra SDR

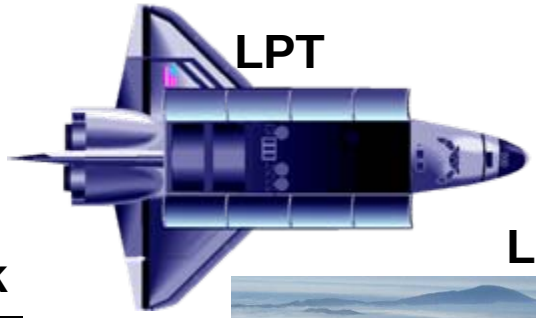
NASA Software Defined Radio Technology in Flight

Blackjack



SRTM

LPT

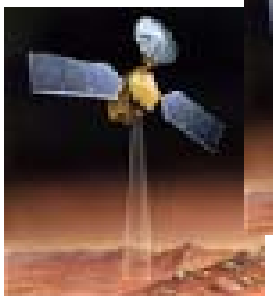


STS-107

LPT

Global Flyer

Electra

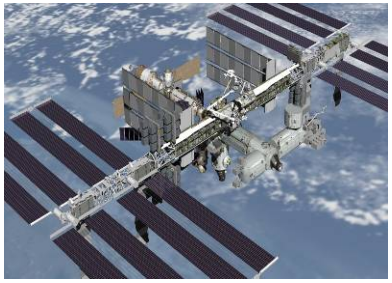


Mars Reconnaissance Orbiter

Electra

Mars Science Lab

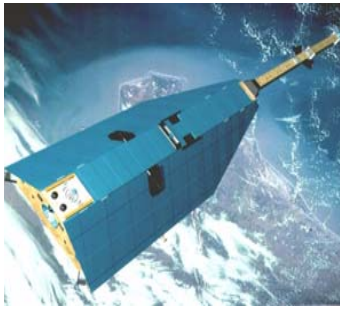
STRS-based SDR Experiment



Comm, Nav, and Networking reConfigurable Test bed

2000 — 2010

Blackjack



Champ

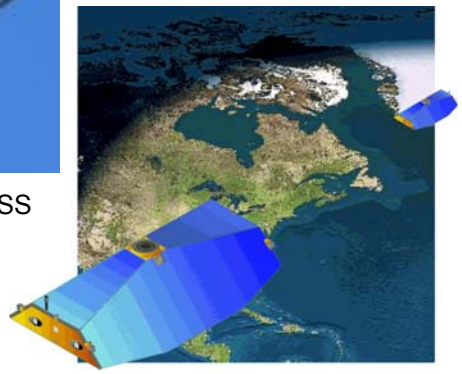
LPT

F-16 AFSS

Blackjack

JASON

Blackjack



GRACE

LPT

AFRL TacSat-2

Space Telecommunications Radio System (STRS) Architecture Introduction

Background

- Agency initiative to infuse SDR Technology and Architectures for NASA missions
- Established ~2005 and composed of engineers from GRC, GSFC, JSC, JPL and APL
- Funded through NASA's Space Communications and Navigation Office (SCaN)

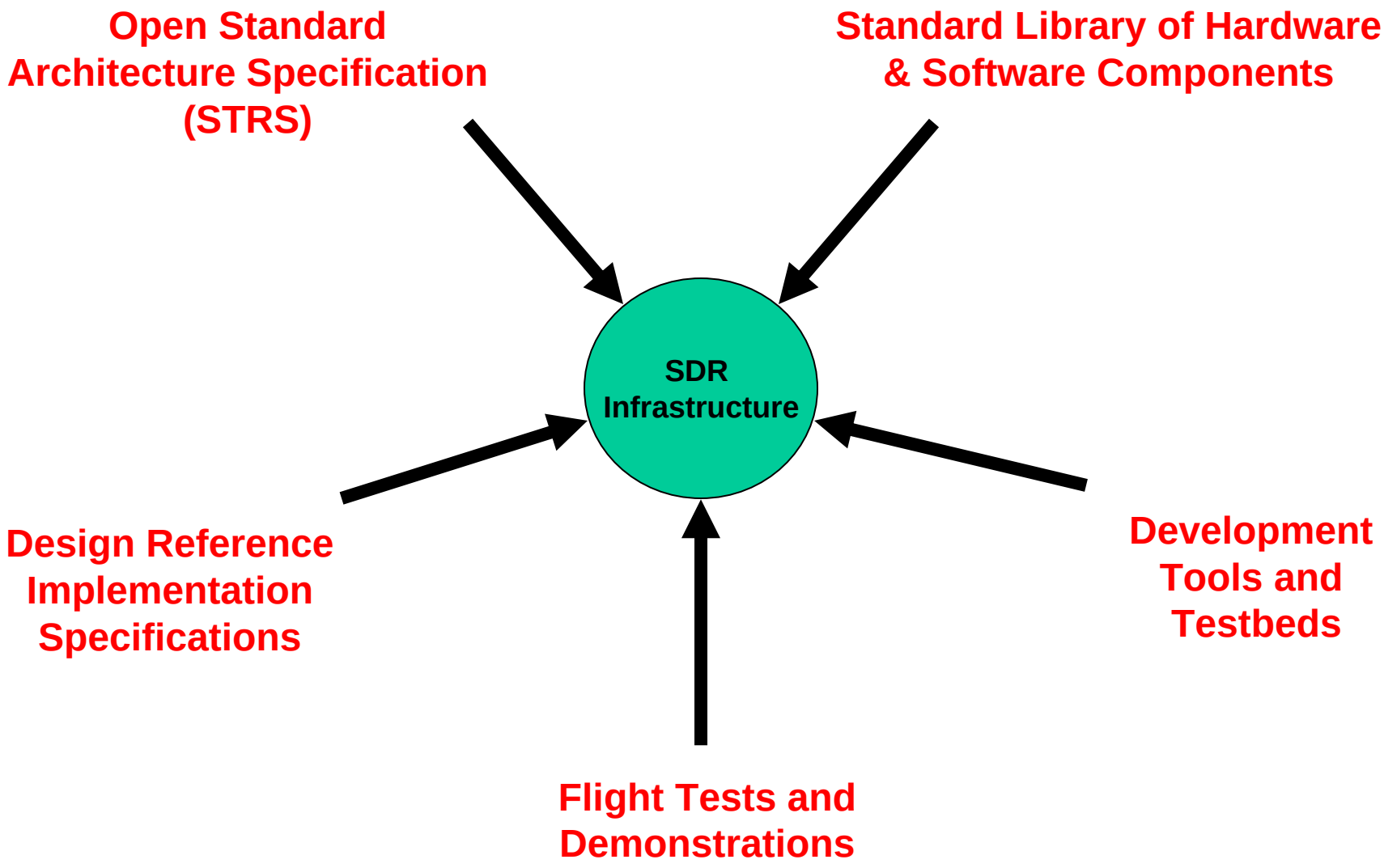
Objectives

- Provide architecture (not implementation) commonality among mission use of SDRs
- Reduce mission risk through reuse of qualified/compliant software and hardware modules among different applications.
- Abstract waveform functionality from platform to reduce mission dependence on single radio/software vendor as waveforms become reconfigurable and evolvable years after development.
- Enables waveform component contributions to repository for reuse

Approach

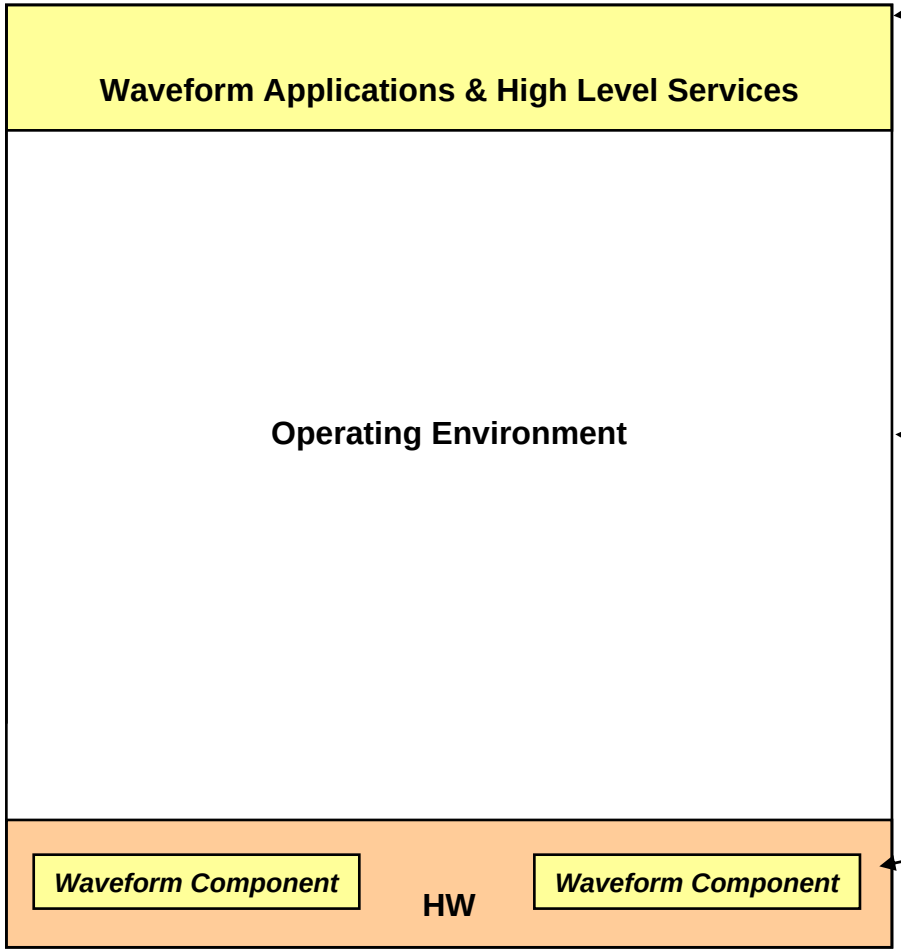
- Standardize functions and interfaces (hardware, software, and firmware) to implement radio communication and navigation for NASA missions (small, med, large)
- Close tie to industry (through SDR Forum) for existing standards, best practices and early acceptance

NASA is Developing a Five-Part Agency SDR Infrastructure to Enhance Acceptance and Use of the Standard



SDR Custom Architecture

Waveform Application and Hardware Interfaces



- Low rate waveform application components allocated to processor based signal processor. High level services used to control and monitor application software

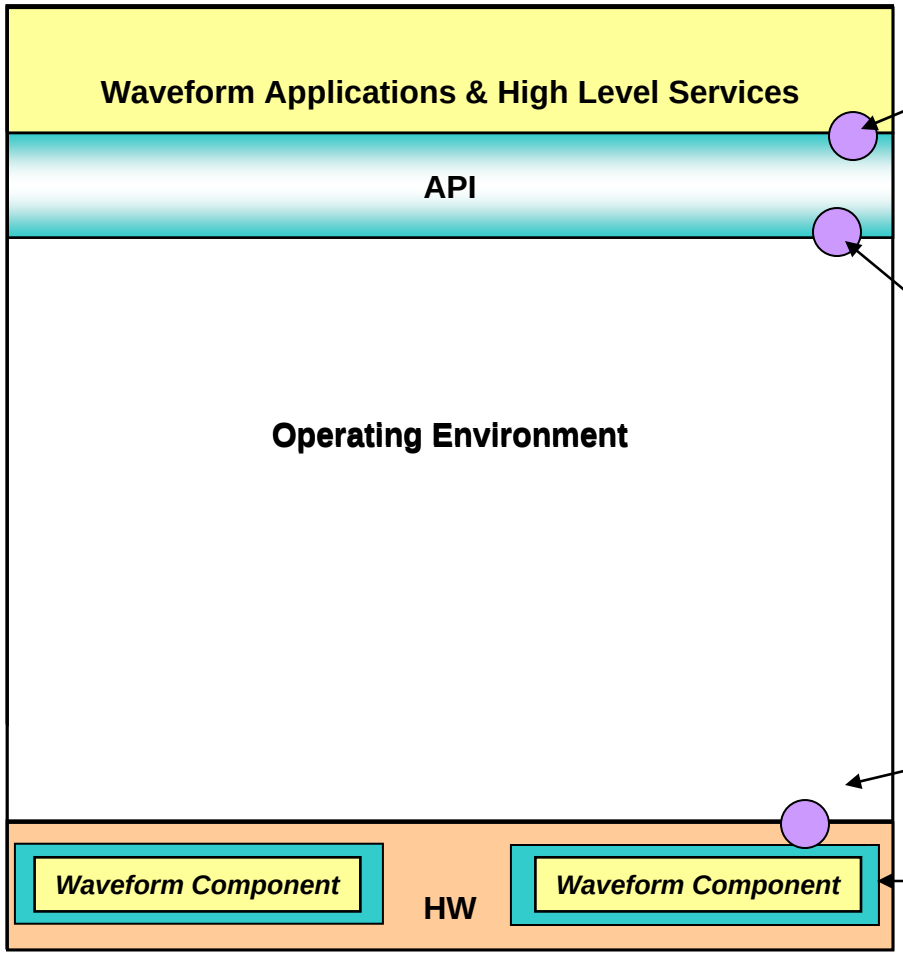
- Operating Environment provides access to processor and specialized hardware for waveform processing

- High rate waveform application components allocated to specialized processing hardware.

- Waveform decomposition driven by designers, not architecture

STRS Open Architecture

Waveform Application API and Hardware Abstraction



- Waveform designers use specified API to access processor and specialized hardware
- APIs specified by architecture separate the waveform from the Operating Environment for waveform portability
- Operating Environment provides published interfaces (API services and hardware abstraction control to waveform)
- Hardware Abstraction Layer (HAL) provides wrapper to help port HDL software among platforms

STRS Open Architecture Platform and Waveform Aspects

Hardware (Platform Compliance)

- Common Hardware Interface Definition (HID)
  - Electrical interfaces, connectors, and physical requirements specified by the mission
  - Power, Mass, Mechanical, Thermal Properties
  - Signals (e.g. Control and Data); Functionality of signals
- Platform Configuration Files
  - Defines a particular instance of an implementation
  - Describes how waveforms are configured
- Common SW Services (STRS Infrastructure)
  - Common API Layer (STRS API set, POSIX abstraction layer)
  - Standard/Published HAL

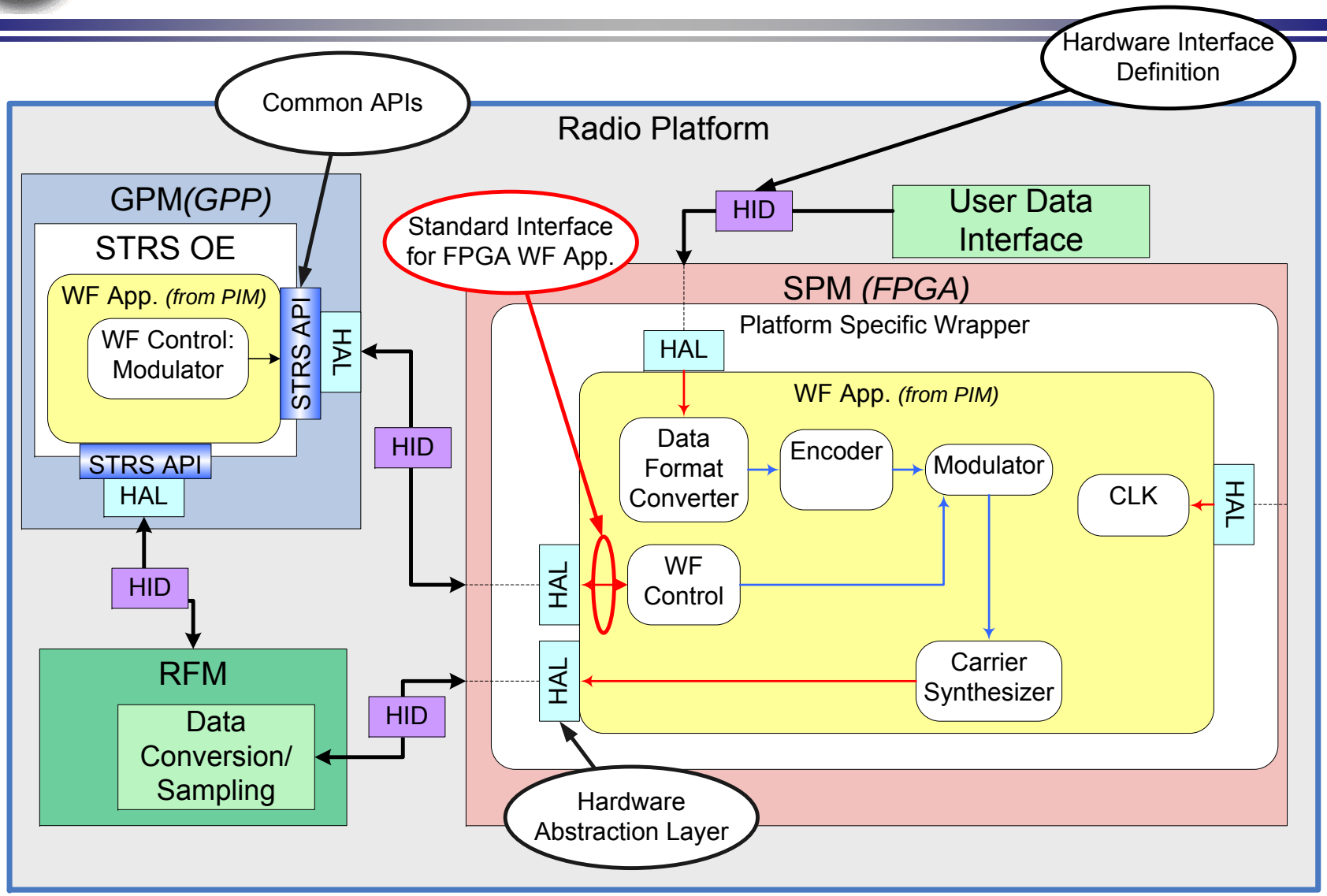
Software (Application Waveform Compliance)

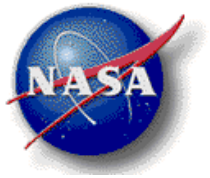
- Adhere to common set of APIs to separate waveform software from platform hardware; portability/reuse

STRS Repository

- Collection of hardware and software modules, definitions, documents for mission reuse
- STRS Documentation aids 3rd party developers with the structure under which they can develop new hardware or software modules

STRS Interface Highlights





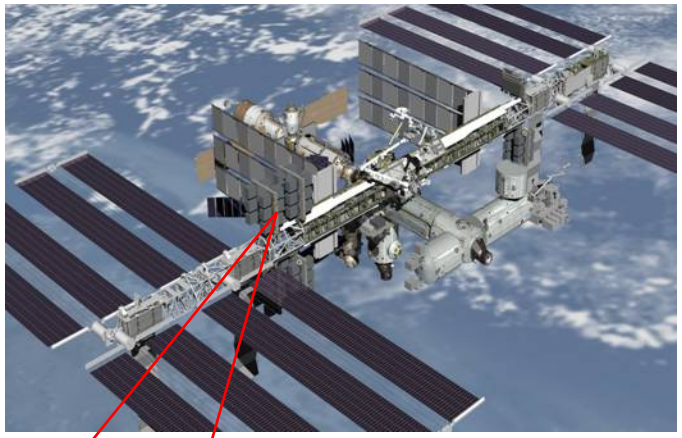
Future Plans for STRS

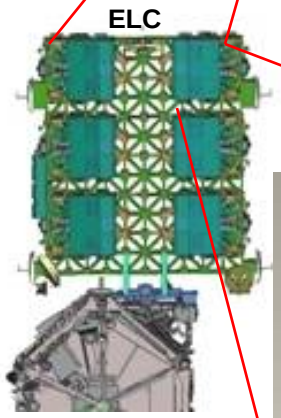
- Near Term
  - Complete reference implementation of current revision (1.01) of architecture
  - Port to flight platforms
  - Assess performance
- Develop Version 2.0 of the STRS Standard
  - Incorporate input from:
    - NASA References implementation
    - SDR Forum comments to STRS document, released Nov 2007
    - Input from other Government Agencies
    - ISS On-orbit Experiment (CONNECT)
  - Add/mature architecture firmware and hardware interfaces
    - Develop approach for Firmware module and interface standardization
- Future versions: Incorporate navigation, ranging, and security aspects into standard

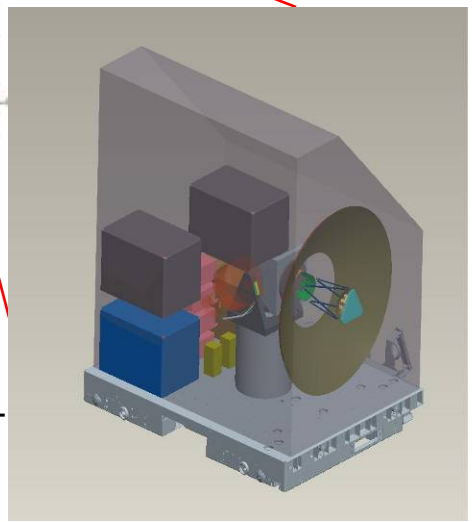
CONNECT
Communications, Navigation, and
Networking reConfigurable Test-bed

Communication, Navigation, and Networking reConfigurable Testbed (CONNECT), ISS Experiment

- Promote development and Agency-wide adoption of NASA's SDR Standard
  - Reduce new technology risk
- Outpost to conduct SDR/STRS-based application experiments in communication, navigation, and networking
  - Addresses specific mission risk areas – e.g., LDPC codes, cross banding, flexible/reconfigurable transceivers
- Move SDR/STRS technologies to TRL 7 – SDR platforms, STRS Standard, software/firmware algorithms, SDR operation, and new GPS bands.







CoNNeCT Payload Concept

Communications, Navigation, and Networking reConfigurable Test bed (CONNECT)

TDRS-2
(275°W)

TDRS-W
(171/174° W)

TDRS-E
(41°/46° W)

On-Orbit Networking Technologies
Disruptive Tolerant Networking Studies
On-board routing, security

Global Positioning System (GPS) Constellation

S-Band

S-Band

S-Band

L-Band

Space Network S-band Communications
Mission Concept & Operations
Adaptive SDR/STRS-based systems
Operational flexibility and capability
Demonstrate Cx, C3I functionality aspects

Next Generation Navigation Techniques
GPS L1 and future L2 and L5
Orbit determination and relative navigation studies

TDRS Space-to-Ground Links

Advance SDR/STRS Communications Technology to TRL-7,
Compliant to STRS Common Architecture
Reprogrammable radio functions
Advancement and improvement of the STRS Standard
Multiple sources of STRS compliant radios

S-Band

S-Band

S-Band

AFSCN

CONNECT SN Data Path

IP Networks

CONNECT GN Data Path

Wallops Island Ground Station

Commercial/ International

ISS TT&C Path

NASA/MSFC/ JSC (HOSC/POIC)

TSC TT&C Path

White Sands Complex

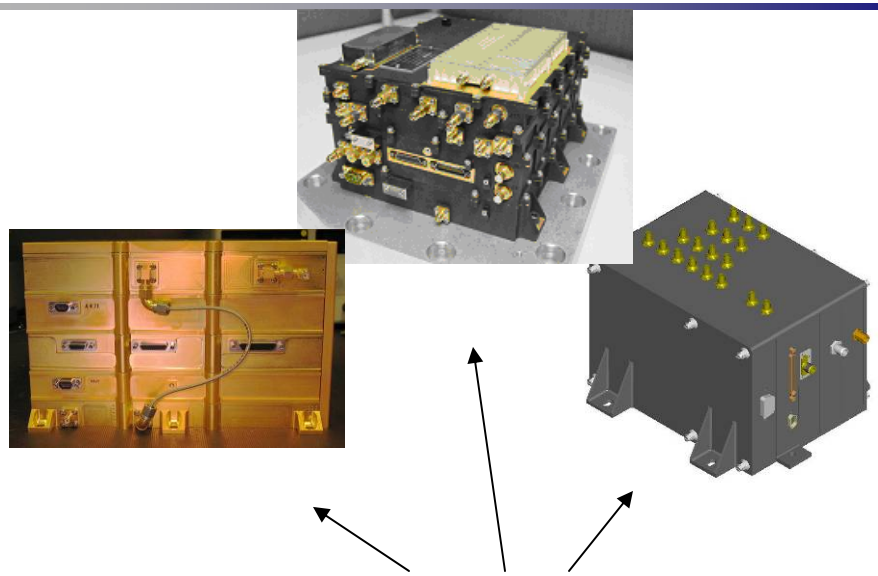
Telescience Support Center Glenn Research Center (GRC)

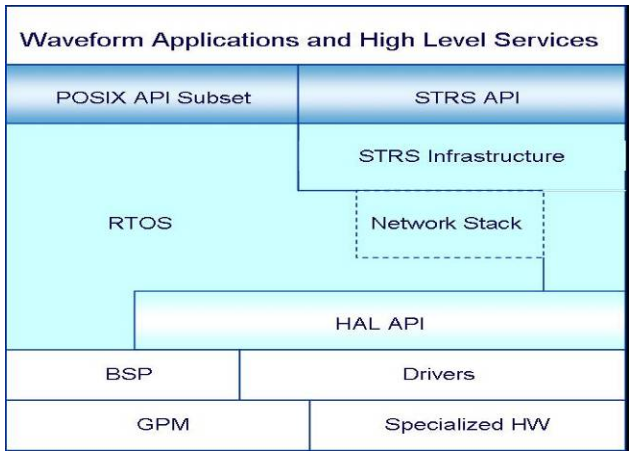
Ground Network Communications

S-band Ground Network Communications
Lunar Surface/Relay Emulation Experiments

SDR/STRS Technology and Communication Experiments Overview

- Advances SDR Technology to TRL-7 for Mission Infusion
  - SDR Performance Assessments (e.g. fault recovery, SEU mitigation)
- Reconfigurability (software updates)
  - Modulation, coding, framing
- STRS Technology Risk Reduction
  - Mature the STRS Standard
  - Mission use and adoption of Standard
  - Transfer STRS to industry and OGA
  - Port sw/fw waveforms among STRS flight platforms
- Industry and NASA Sources of STRS Compliant Flight Radios
- TDRSS Access Techniques (MA, SA)
- Simultaneous Applications (TDRSS/GPS)

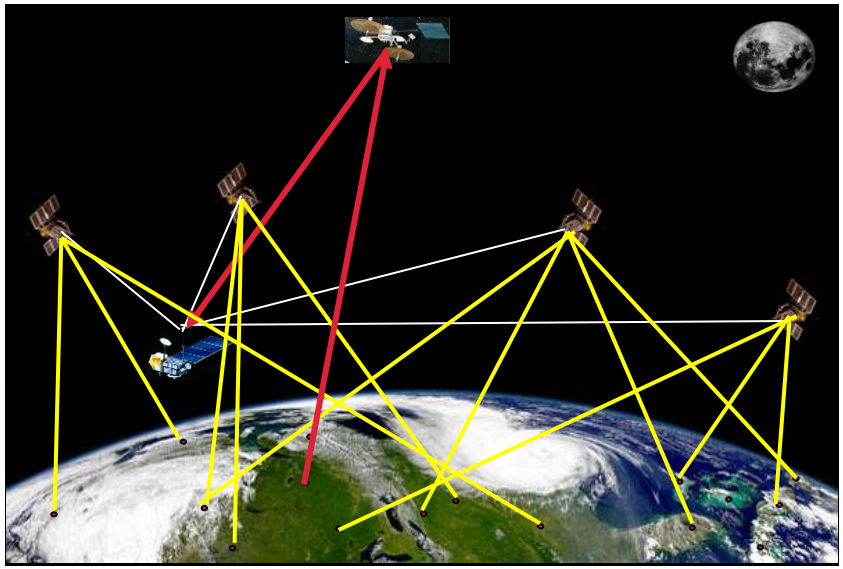




Single SDR Standard, among different implementations

Navigation Experiments Overview

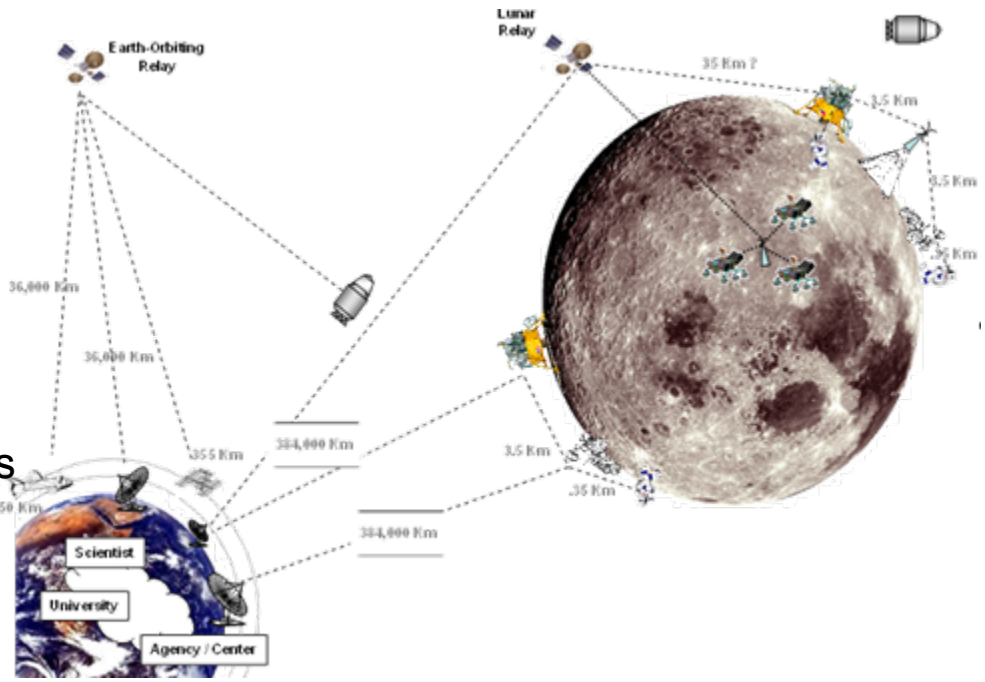
- Characterize SDR-based GPS Receiver Performance, Real-time Positional Solution and Tracking Capability.
- GPS Tracking on ISS using L1, L2, and L5 Signals with Real-time Positional Solution.
- Develop The TDRSS Augmentation Service for Satellites (TASS) to relay in real-time GPS augmentation message to spacecraft, and near-Earth Exploration
  - In-situ Validation Of TASS On ISS
  - Validate Decimeter Fidelity Accuracy And Nano-second Time Sync
- Demonstrate Coherent Flexible Turnaround
- Two-way Doppler-based Track Updates to Validate Turnaround Coherency



Augmented GPS position determination using SDR and Future GPS signal assessments

Networking Experiments Overview

- Network-Centric Operations on Orbit
  - On-board routing and/or relay function
  - Risk reduction for Constellation/Lunar
- Demo New Networking Protocols, Standards, and Operational Concepts
- Disruptive Tolerant Network (DTN) ops Concepts and Protocol Demonstrations
  - Increased TRL for space internetworking technologies
- Static Routing Between Multiple RF Paths
- Dynamic Routing Between Multiple RF Paths Based on Access Time and Best Signal Level
- Priority Based Data Routing Over Multiple RF paths (e.g., housekeeping, data)
- Demonstrating AES Encryption and Authentication Techniques



Example of Lunar network connectivity

SDR & STRS Architecture Conclusions

- Reconfigurable SDR will enable new mission concepts
  - Remote/autonomous operations
  - Future cognitive radios
- STRS Architecture provides commonality among reconfigurable SDRs developed by NASA
  - Provides a coordinated method across the agency to apply SDR technology
  - Program/mission risk reduction
  - Allows technology infusion
  - Reduces vendor dependence
- STRS Architecture will evolve before becoming a required standard
  - Waveform Control
  - Navigation, Security, Networking…
  - Leverage best aspects of JTRS SCA, OMG's SWRadio and industry practice
- The CONNECT ISS Experiment will prove out STRS among multiple SDRs in space environment

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