National Aeronautics and Space Administration

Pulsar Navigation & X-ray Communication Demonstrations with the NICER Payload on ISS

Presented by
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Station Explorer for X-Ray Timing and Navigation Technology (SEXTANT)
NASA GSFC

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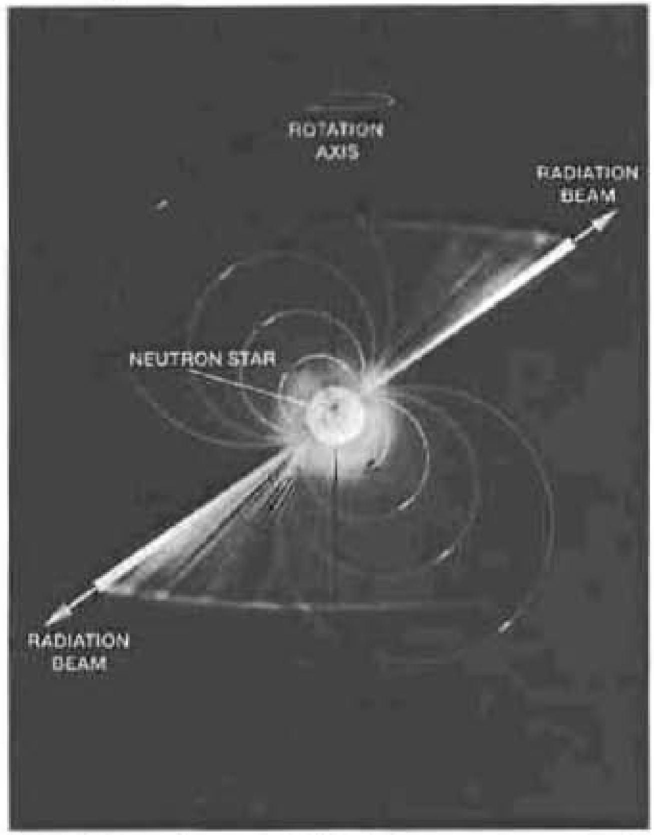
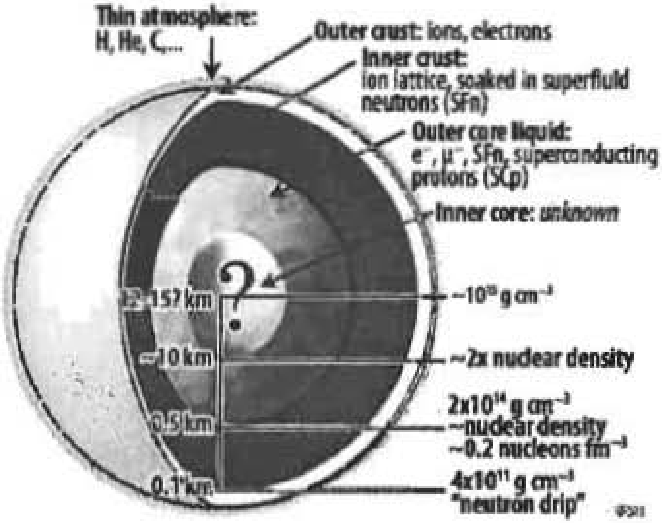
Outline

- Neutron-star Interior Composition ExploreR
- Mission naming
- People
- Mission commonality
- Goals
  - Navigation
    - Ground testbed
  - Communication
- Challenges
- Future activity



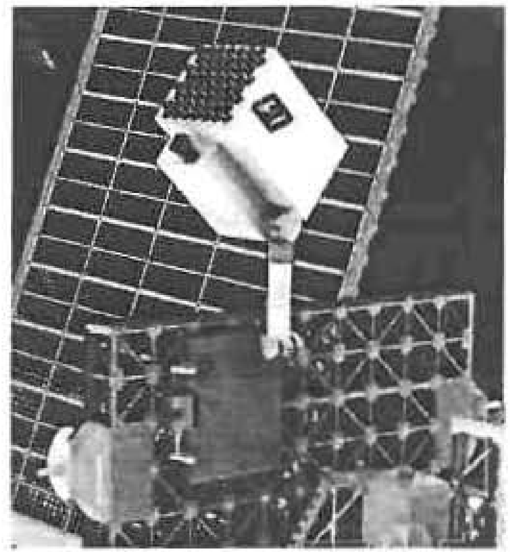
NICER — Science Objectives

- Address NASA and National Academy of Sciences strategic questions
  - Resolve the nature of *ultra-dense* matter at the threshold of collapse to a black hole
  - **Structure**—Reveal the nature of matter in the interiors of neutron stars
  - **Dynamics**—Uncover the physics responsible for the dynamic behavior of neutron stars
  - **Energetics**—Determine how energy is extracted from neutron stars



Project Names & Definitions

- NICER — Neutron-star Interior Composition ExploreR
  - ISS ELC Explorer Payload (2016/09/02)
  - Observe pulsars in X-ray part of EM spectrum
  - Determine pulsar radii and masses
  - SMD selected *purely* on science (Phase A)
- SEXTANT — Station Explorer for X-Ray Timing and Navigation Technology
  - Same instrument used for NICER
  - Navigation (XNAV) and communication (XCOM)
    - XCOM: payload is X-ray receiver
    - XNAV: advanced algorithms, measurement processing
  - Enhanced avionics/algorithms required over NICER baseline

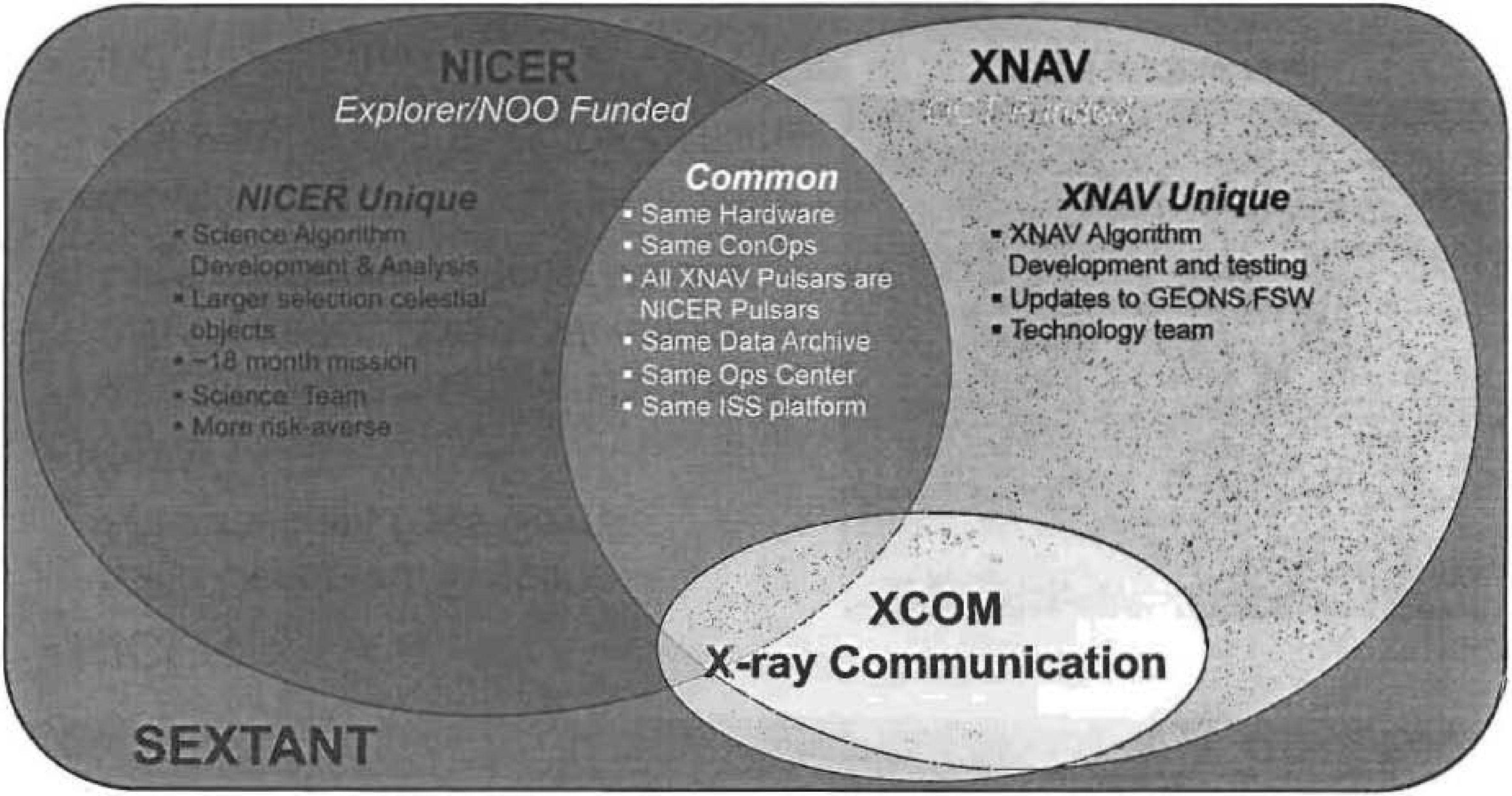


Project Team Overview

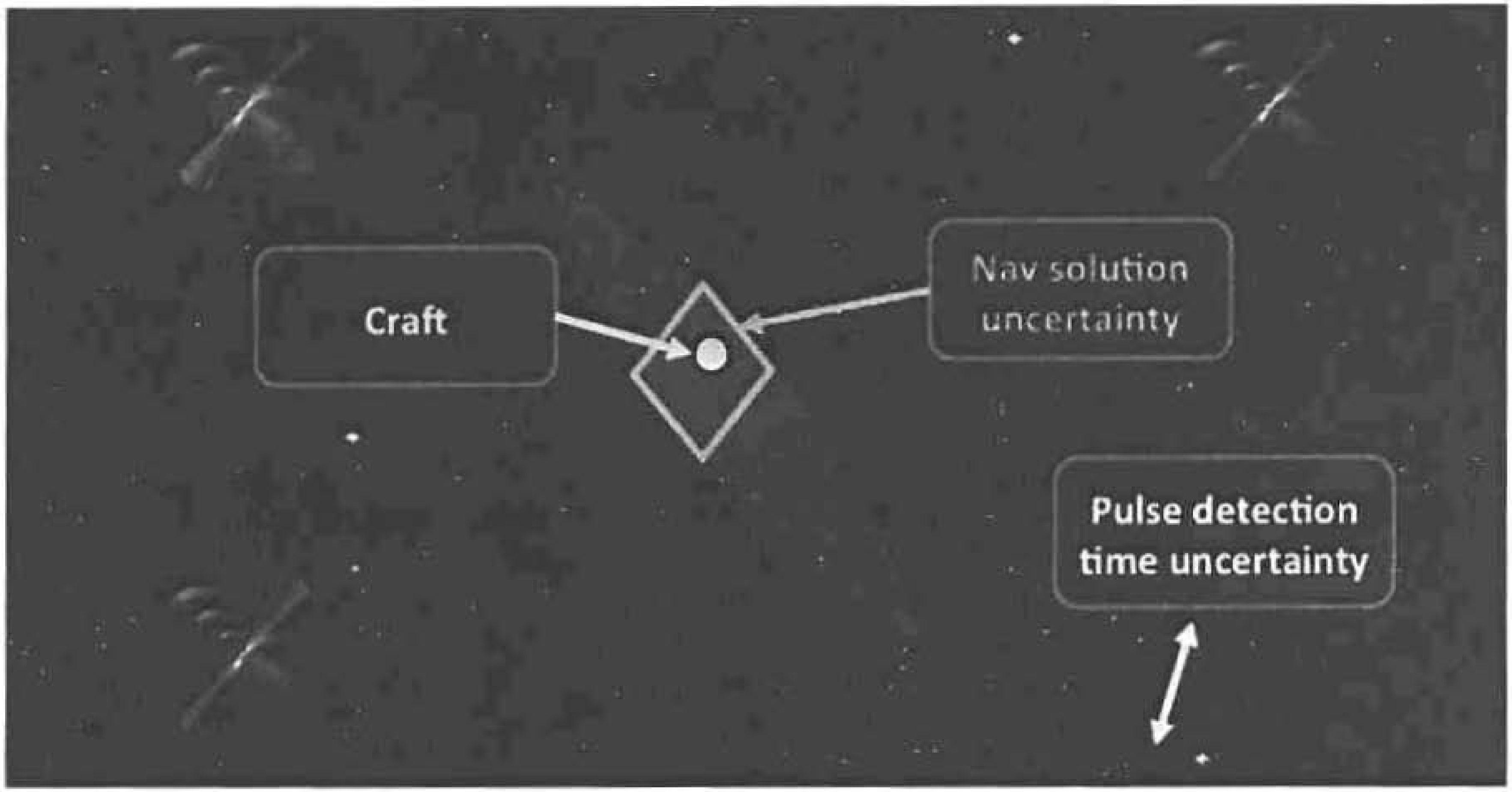
- NICER
  - Keith Gendreau, Zaven Arzoumanian, Fotis Gavriil
- XNAV
  - Jason Mitchell, Monther Hasouneh, John Gaebler, Dennis Woodfork, Luke Winternitz, Jennifer Valdez
- XCOM
  - Wai Fong, Victor Sank, David Fisher
- And many, many more!
  - many external partners too!

Portion of XNAV Team

Mission Commonality: SEXTANT = NICER + XNAV + XCOM



Basic Navigation



XNAV Concept

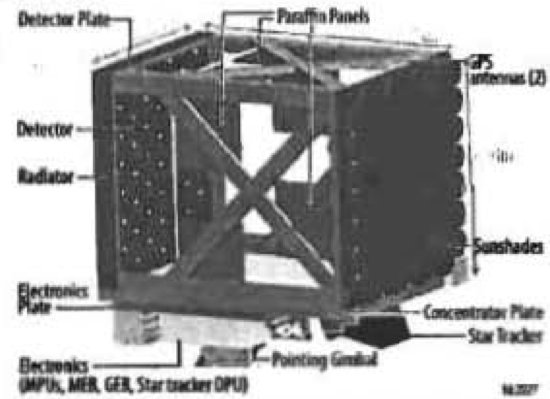
- Precise timing enables improved navigation
  - Pulsars: rapidly spinning neutron stars
  - Millisecond pulsars (MSPs)
    - rival atomic clocks as time-keepers
    - accuracy & stability
  - Potentially provide *galaxy-wide* time-base
    - GPS-like navigation capability throughout solar system

Crab Pulsar (slowed), Cambridge University, Lucky Image Group

- Measurement
  - Precisely time tag X-ray photons
  - Pulse arrival time, i.e., pulsar *pseudo-range*
  - Stitch sequence together for autonomous navigation solution
- Interested agencies: NASA, DoD (DARPA), NIST

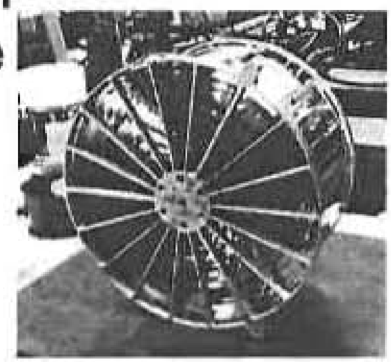
SEXTANT / XNAV Goals

- Provide *1st on-orbit demo* of XNAV concept
  - LEO worst case scenario
  - Real-time 1D range < 1 km from 2–3 pulsars / orbit
  - XNAV-only 3D position to ~500 m @ 1 day
  - Understand sky distribution effect on dilution of precision
  - Long-term characterization of pulsar clock stabilities
  - Characterization of additional candidate pulsars
- Other benefits
  - Active X-ray timing observatory, RXTE decommissioned
  - Improved sensitivity over RXTE, XMM-Newton



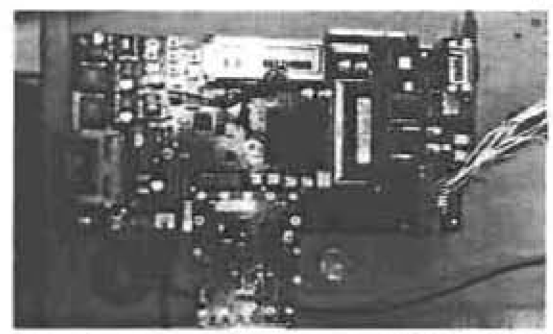
SEXTANT / XNAV Elements

- Improved X-ray concentrator optics
  - Large collecting area, small volume



- Silicon drift detectors
  - Time resolution < 200 ns
- Algorithms
  - Relativistic time-transfer, pulsar range estimator, XOD

- GSFC Navigator GPS technology
  - Precise reference to UTC

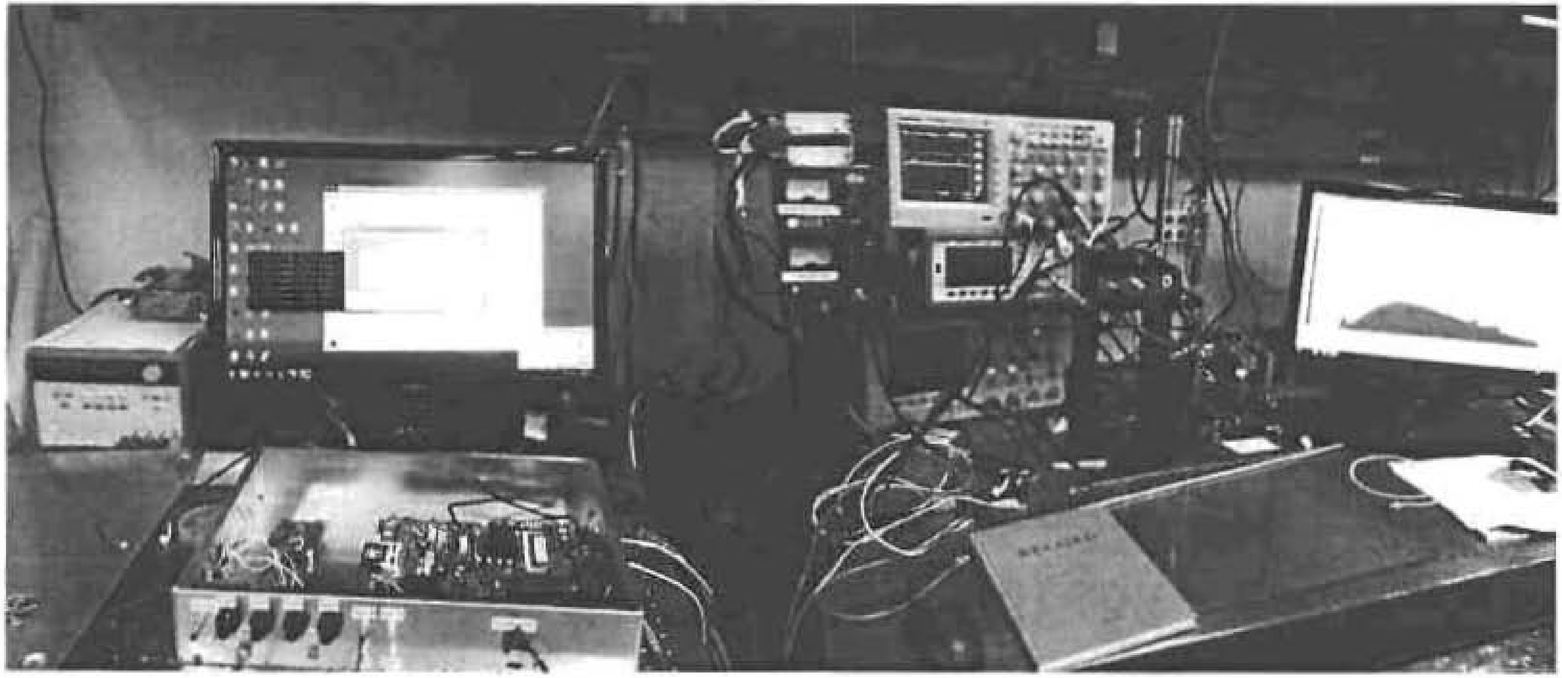


- MSP Emulator
  - Miniaturized modulated X-ray source
  - EDU time-tagging X-ray photon detector

Goddard XNAV Laboratory Testbed (GXLT)

- Guided incremental multi-milestone development plan
- Leverages Goddard GN&C (Code 590) software tools
  - Mission design: General Mission Analysis Tool (GMAT)
  - Orbit determination:
    - Orbit-determination toolbox (ODTBX) for MATLAB
    - Goddard Enhanced On-board Navigation System (GEONS) flight software
  - GPS receiver (Navigator GPS) design and expertise
- Support algorithm development & testing
- Prepare & transition algorithms to flight software
- Standardized interfaces defined to foster collaboration

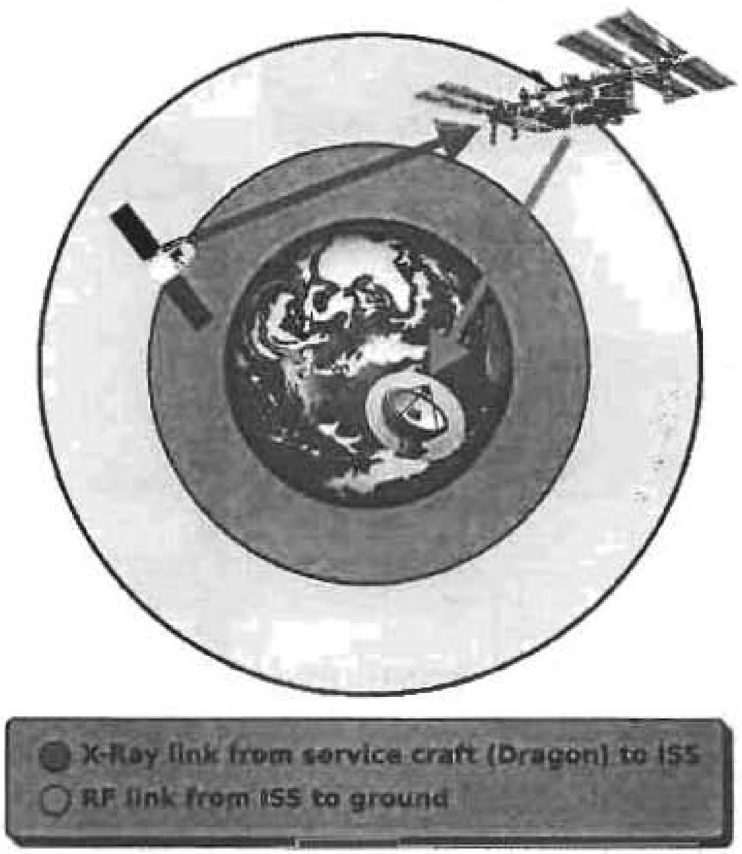
Current GXLT Progress



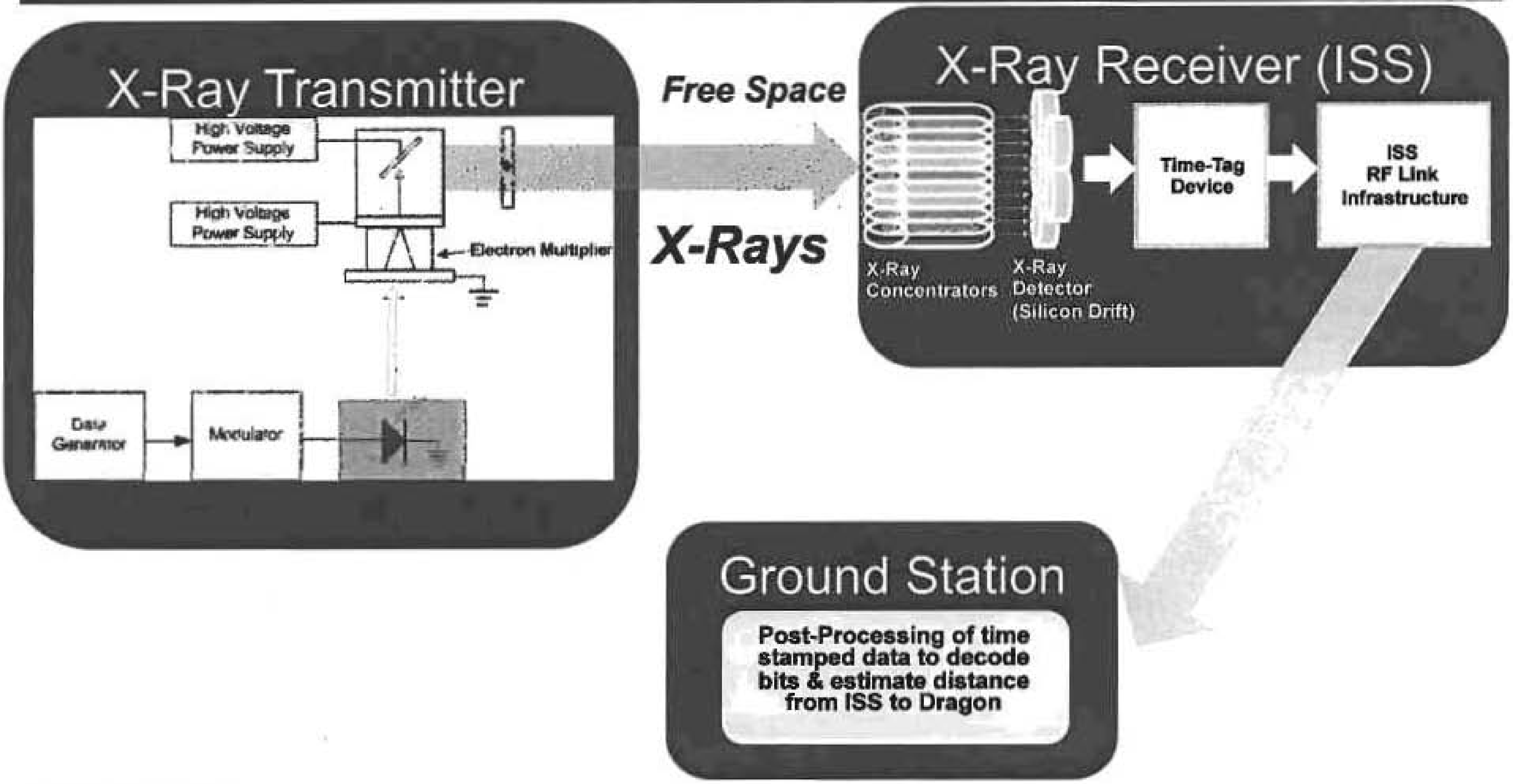
Real-time MSP emulation

XCOM Experiment Concept

Range: 25 to 1000 km



X-ray Comm. Link System Block Diagram



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Technical Challenges

- Launch: HTV or Dragon
  - Huzzah to SpaceX
- Address Crab PSR high photon count rates
- Observing sufficient photons from low-count-rate pulsars
  - accurate measurements challenging in high dynamics
- Choice of coordinate time
  - TDB vs. TCB
- GPS and timing accuracy on ISS
  - Multi-path effects from geometry
  - SV visibility & geometry
  - High time accuracy

Future Activity

- Complete Step 2 concept study report
  - Due mid-Sep 2012
- Demonstrate GXLT, real-time, hardware-in-the-loop
- Broad improvements to modeling fidelity
- Extensive algorithm testing
- EDU hardware integration
- Flight software development & integration
- S/C integration & test