

NICER

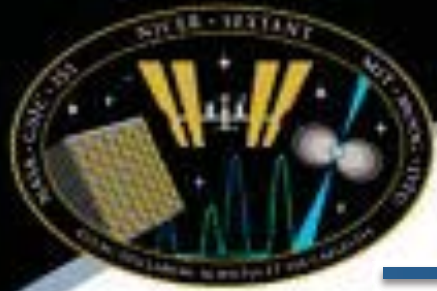
Neutron star Interior Composition Explorer

Station Explorer for X-ray Timing and Navigation Technology (SEXTANT)

Jason Mitchell, Ph.D.
SEXTANT PM

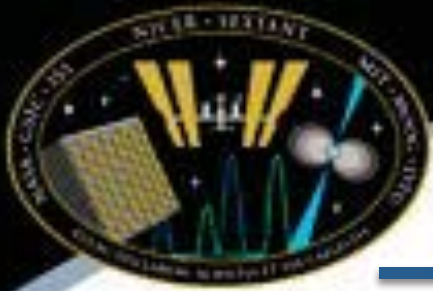
AIAA GN&C Conference
Kissimmee, FL Jan 5—9, 2015





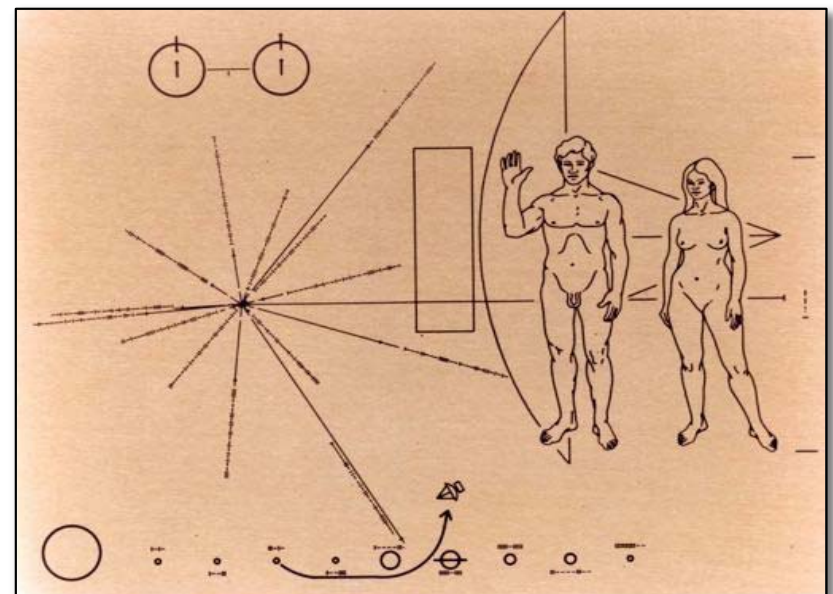
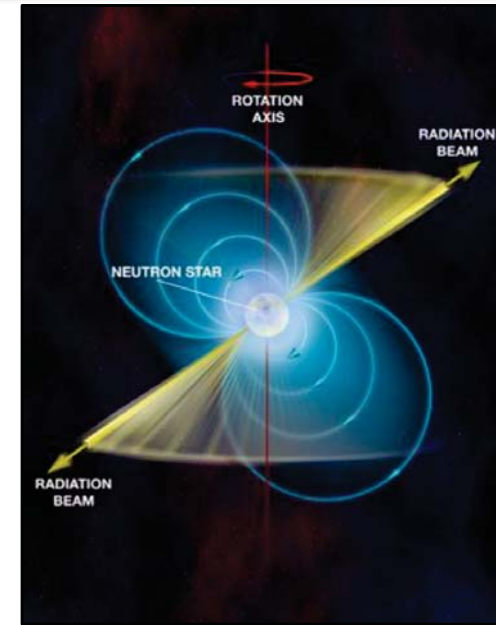
Outline

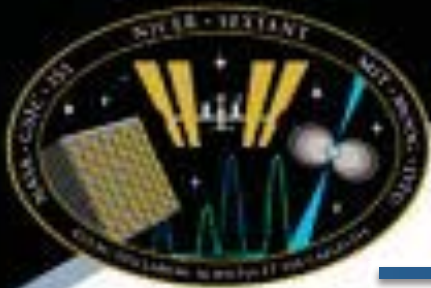
- X-ray pulsar Navigation (XNAV)
 - Background
 - Concept
- Missions
 - NICER, primary science mission
 - SEXTANT, companion technology demonstration
- Architecture
 - NICER X-ray Timing Instrument (XTI)
 - Flight software
 - Ground testbed and end-to-end simulation
 - Ground system
- Future activity



X-ray pulsar Navigation (XNAV)

- Pulsars were discovered in 1967 and immediately recognized as a tool for Galactic navigation
- Millisecond pulsars (MSPs)
 - Rival atomic clocks as time-keepers on long time scales (>year)
 - Pulse phase and Doppler can be precisely measured
 - Provides GPS-like nav & time throughout solar system and beyond
 - MSPs are distributed throughout the Galaxy

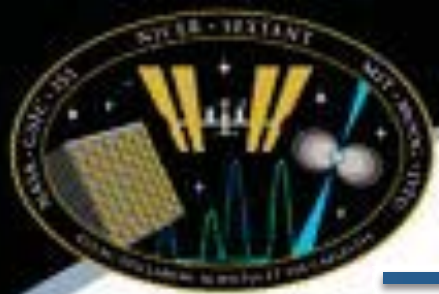




XNAV Development History

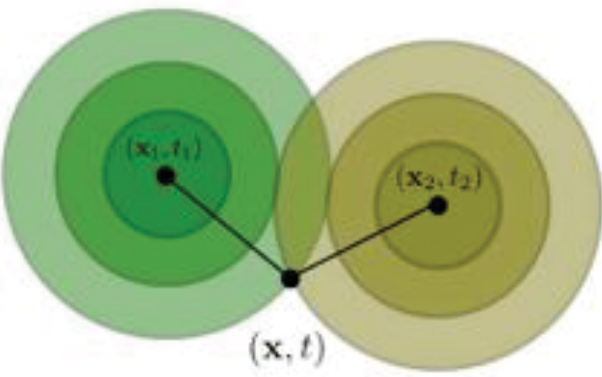
- XNAV has rich history beginning with discovery of first radio pulsar
 - Significant body of published research
- Naval Research Laboratory (NRL) (1999-2000)
 - Unconventional Stellar Aspect (USA) Experiment
- DARPA XNAV Project (2005-2006)
 - Ball Aerospace collaborated with Microcosm Inc.
 - Algorithms, Infrastructure
 - Detector and Pulsar modeling studies (NRL)
 - Modulated X-ray Source (MXS) developed, Gendreau
- DARPA XTIM (2009-2012) continuation DARPA XNAV, led by Lockheed with Ball Aerospace
 - Used Large Area Collimated Detector
- NASA SBIRs with Microcosm
- NICER / SEXTANT selection 04/2013
 - SEXTANT team deeply involved in prior programs
 - Evolution of XNAV detector ideas shows NICER XT1 (concentrating optics/ silicon det) to be practically ideal
- ***Prior work has set the stage for SEXTANT to perform the full onboard XNAV OD***



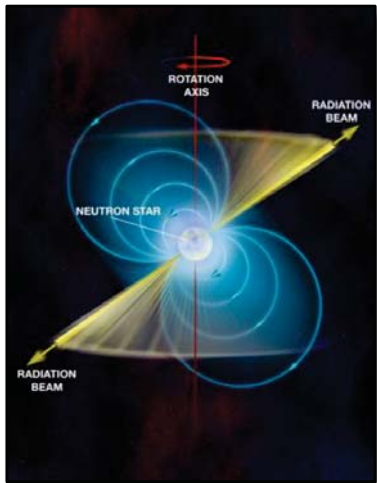
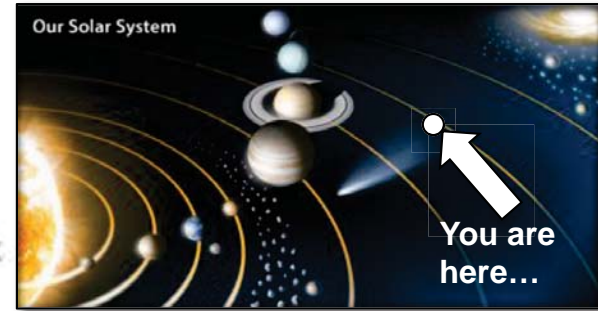
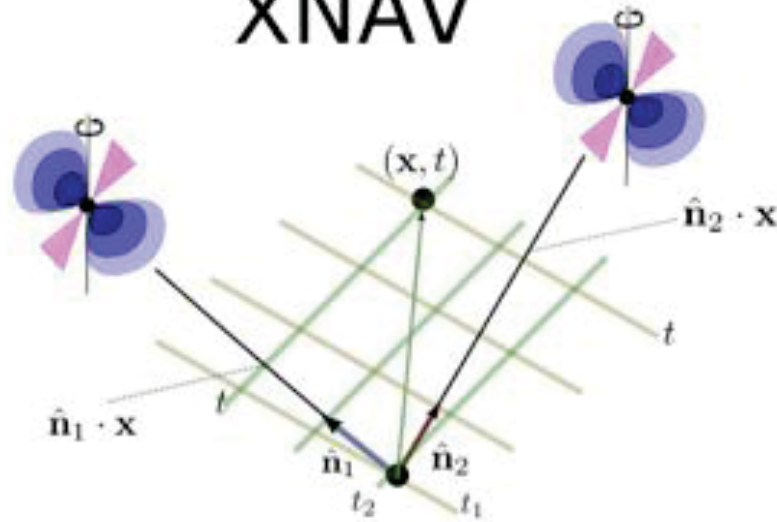


XNAV Demonstration Concept

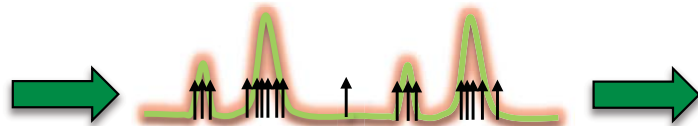
GPS



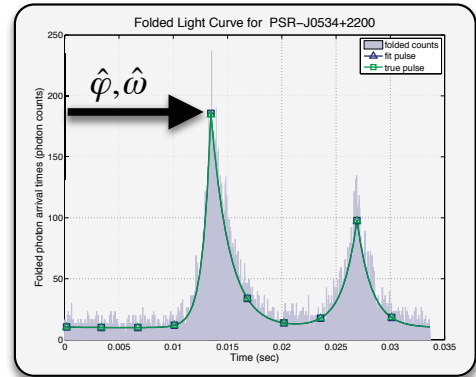
XNAV



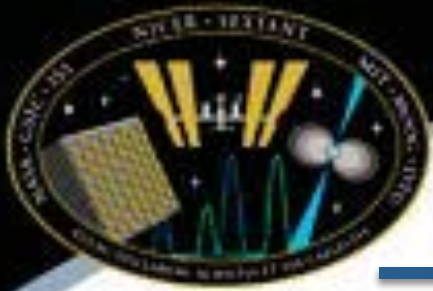
X-ray photons



NICER Instrument

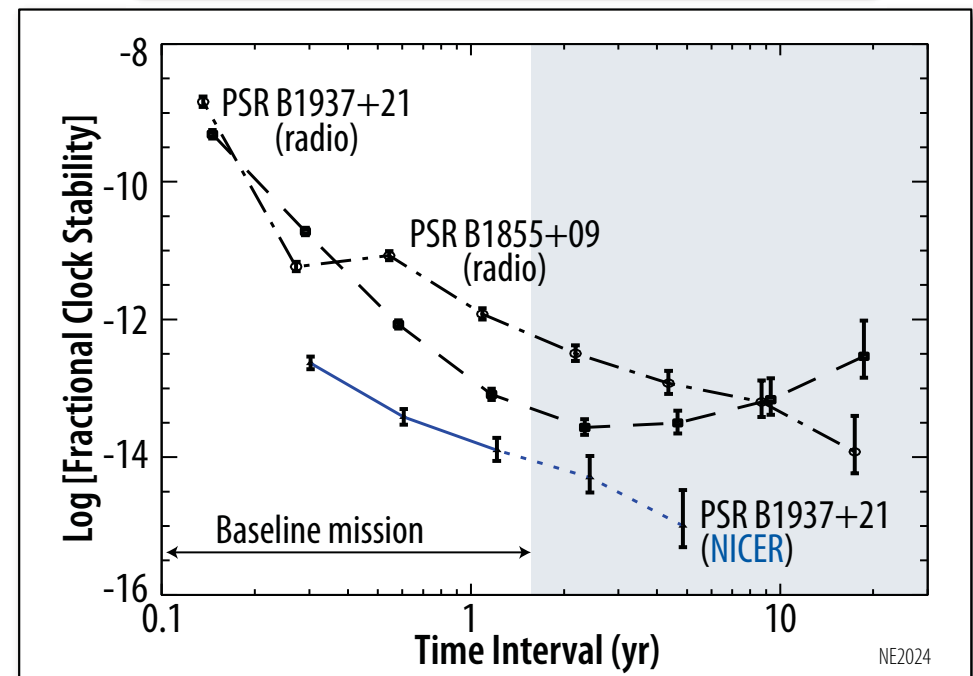
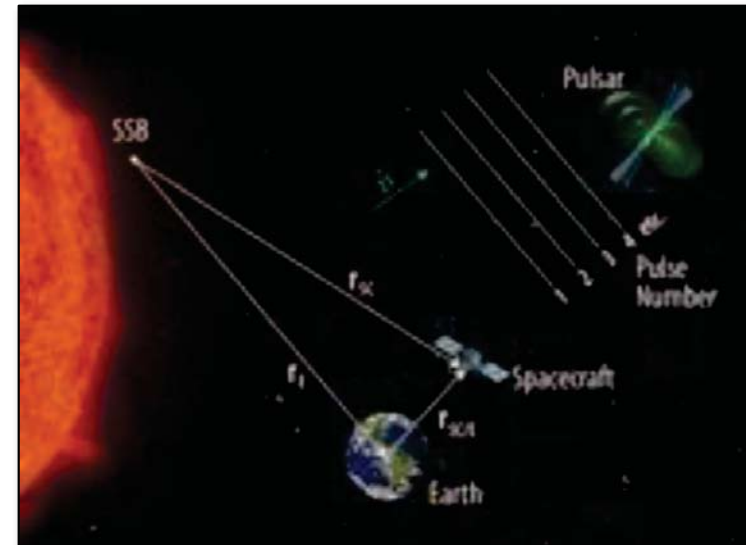


SEXTANT algorithms



SEXTANT Overview

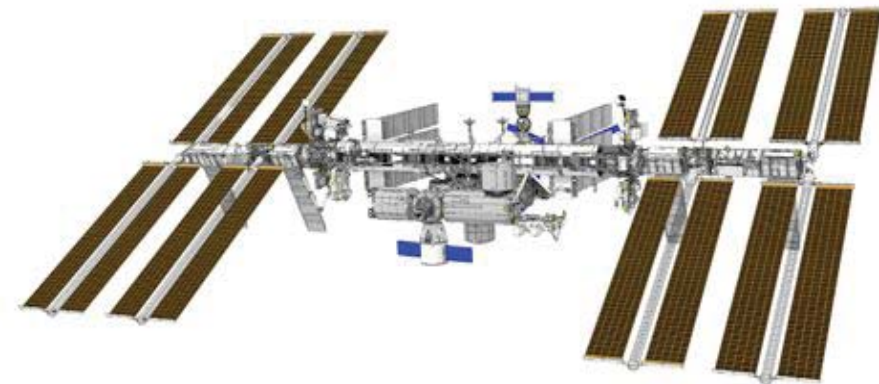
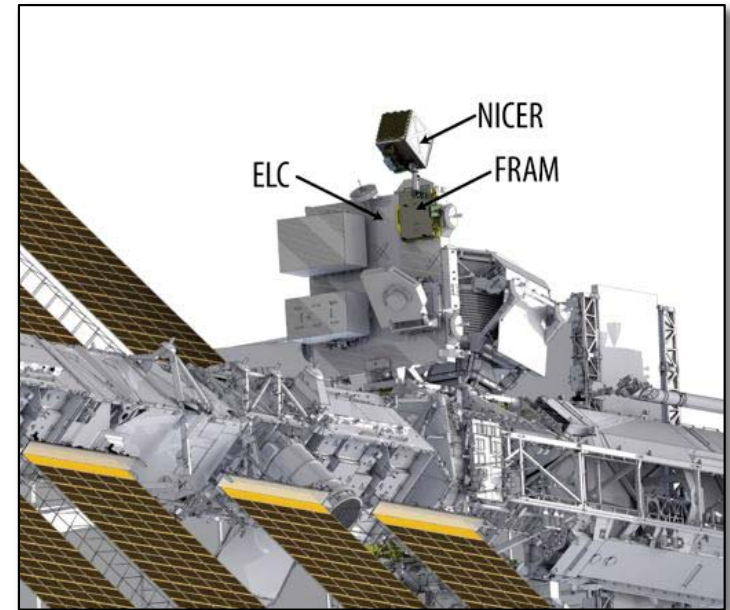
- Station Explorer for X-ray Timing and Navigation Technology (SEXTANT)
 - STMD/GCD funded technology enhancement to NICER
 - Will be 1st demo of real-time, on-board X-ray navigation (XNAV)
- Concept context
 - Pulsars are neutron stars that appear to pulsate across the electromagnetic spectrum, but are bright enough in X-rays to enable XNAV instrumentation & solutions
 - Some millisecond pulsars (MSPs) rival atomic clocks in long-term timing stability
 - Pulse Time of Arrival (TOA) deviations can update spacecraft dynamics model along line of sight
 - Observing multiple MSPs can yield 3D orbit data

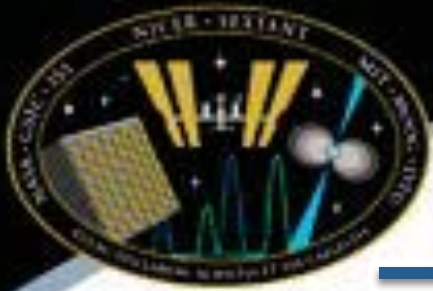




Neutron-star Interior Composition Explorer (NICER)

- NICER
 - SMD competitively selected purely on science
 - Fundamental investigation of *ultra-dense* matter: structure, dynamics, & energetics
 - Launch in Oct 2016 on Space-X Dragon
 - 18 Month mission on Express Logistics Carrier (ELC)
 - X-ray (0.2–12 keV) *concentrator optics* and silicon-drift detectors; GPS position and 300 ns absolute time tagging
- SEXTANT — Station Explorer for X-Ray Timing and Navigation Technology
 - STMD funded technology enhancement to use NICER
 - Demonstrate X-ray pulsar navigation (XNAV), enable other applications
 - Only enhanced flight software on NICER, same hardware





SEXTANT Demonstration Objective

- **SEXTANT Primary Objective**

Provide first demonstration of real-time, on-board X-ray Pulsar Navigation

- *Primary Objective: 10 km orbit determination accuracy, worst direction, 2 weeks*
- Implement a fully functional XNAV system in a challenging ISS/LEO orbit; NICER compatible
- Advance XNAV technologies

- **Secondary Objectives**

- Repeat XNAV demo with new NICER data & new MSP discoveries
- Validate & enhance the unique Goddard XNAV Lab Testbed (GXLT)
- Use SEXTANT data & GXLT to study real-world XNAV scenarios
- Evaluate candidate photon processing & navigation algorithms & develop new techniques
- Study utility of pulsars for time keeping & clock synchronization

- **Planned Experiments**

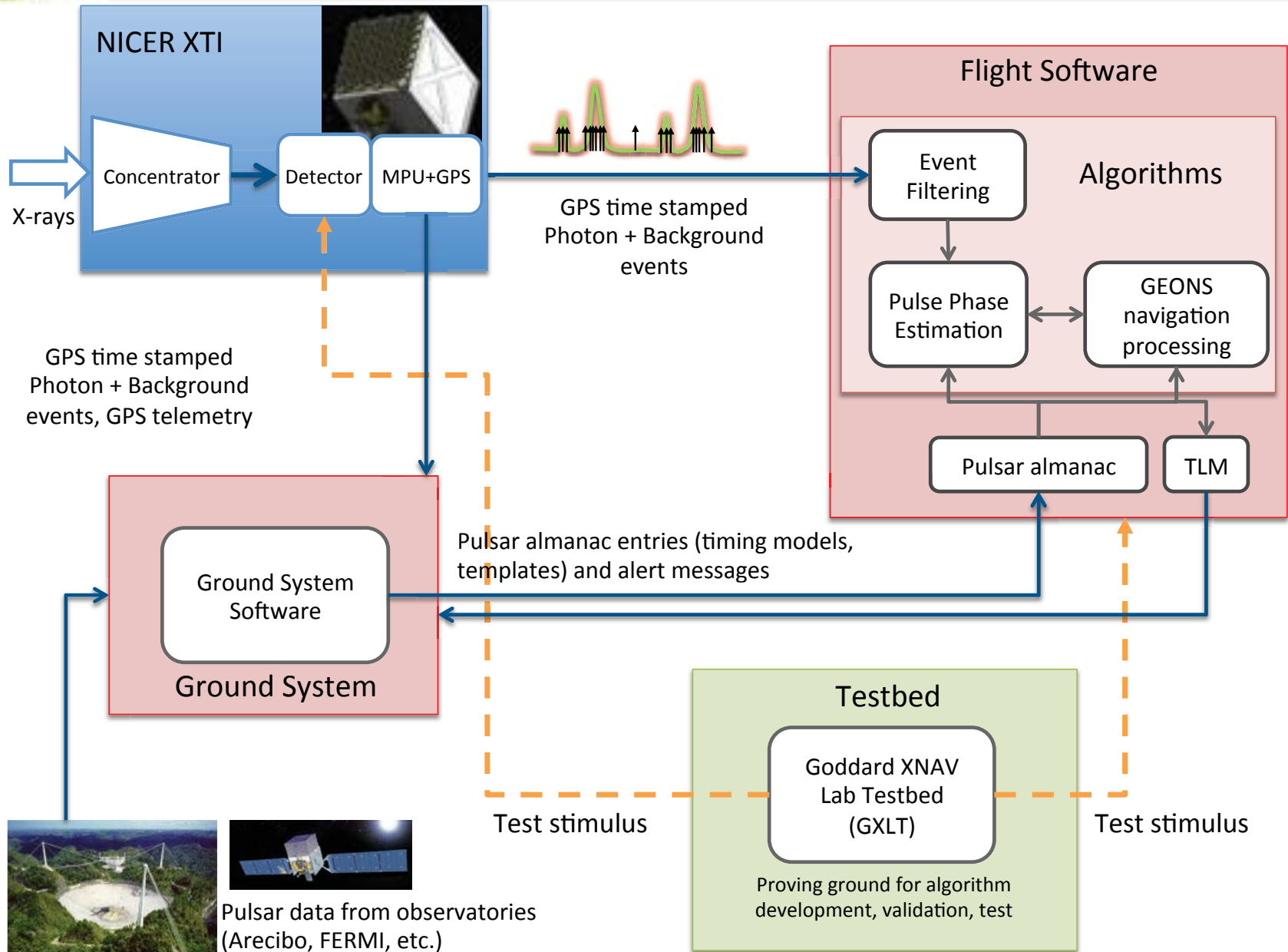
- 2-week period observing 3 – 5 pulsars early in the mission (primary)
- Opportunistic experiments
- Ground experiments using collected photon data

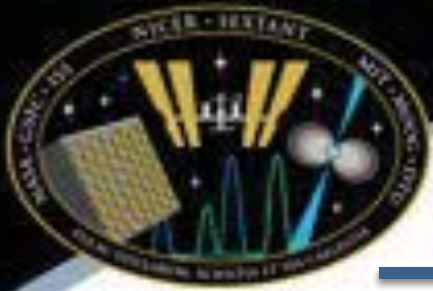
- **Stretch Objective**

- *1 km orbit determination accuracy, worst direction, using up to 4 weeks of observations.*



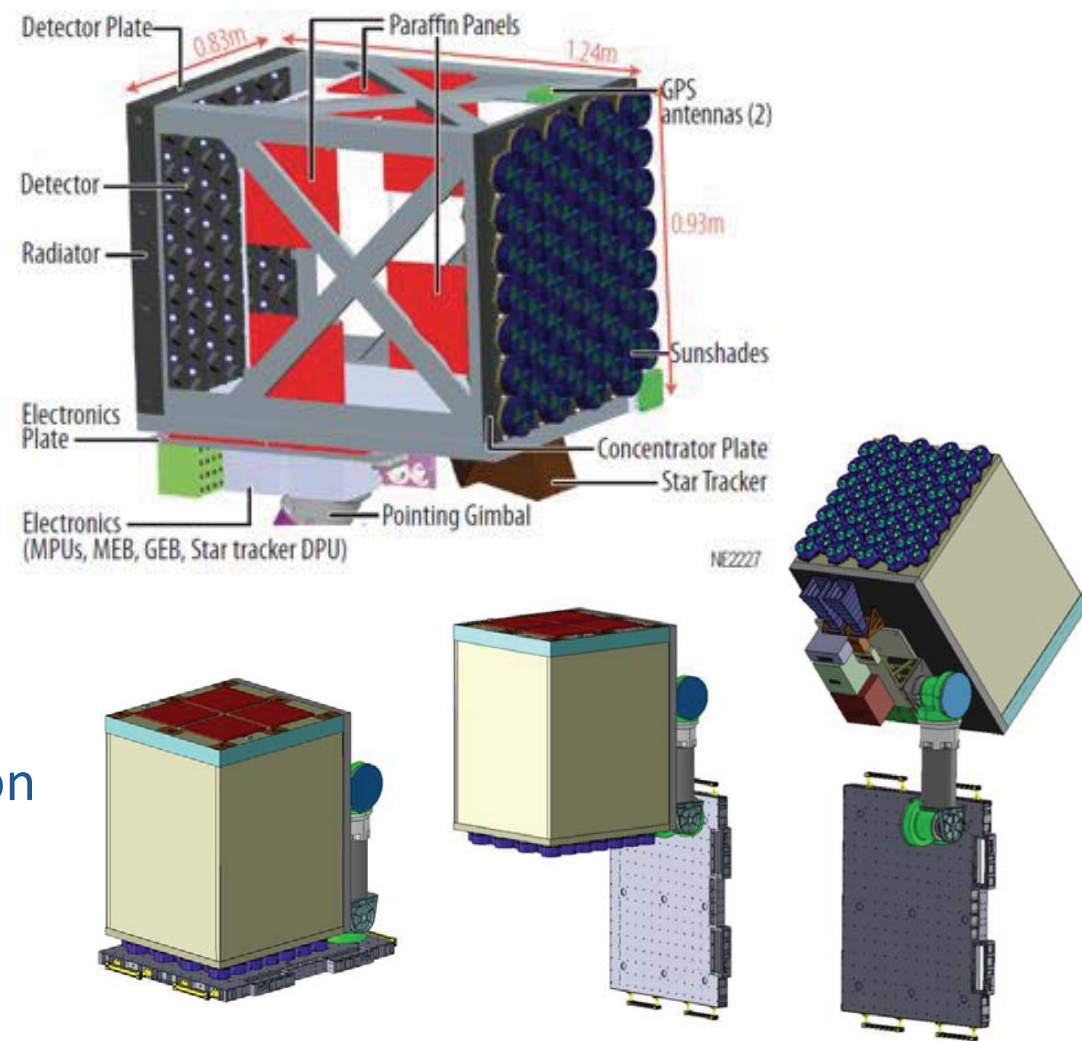
SEXTANT System Architecture





NICER X-ray Timing Instrument (XTI)

- 56 co-aligned X-ray concentrator optics and associated Silicon Drift Detectors (SDDs) in Focal Plane Modules (FPMs)
- 7 Measurement/Power Units (MPUs)
- The FPMs detect X-rays arriving from the concentrators
- MPUs time-tag and packetize photon events
- < 300 nsec absolute time resolution
- > 2000 cm² effective area
- Moderate (CCD-like) energy resolution

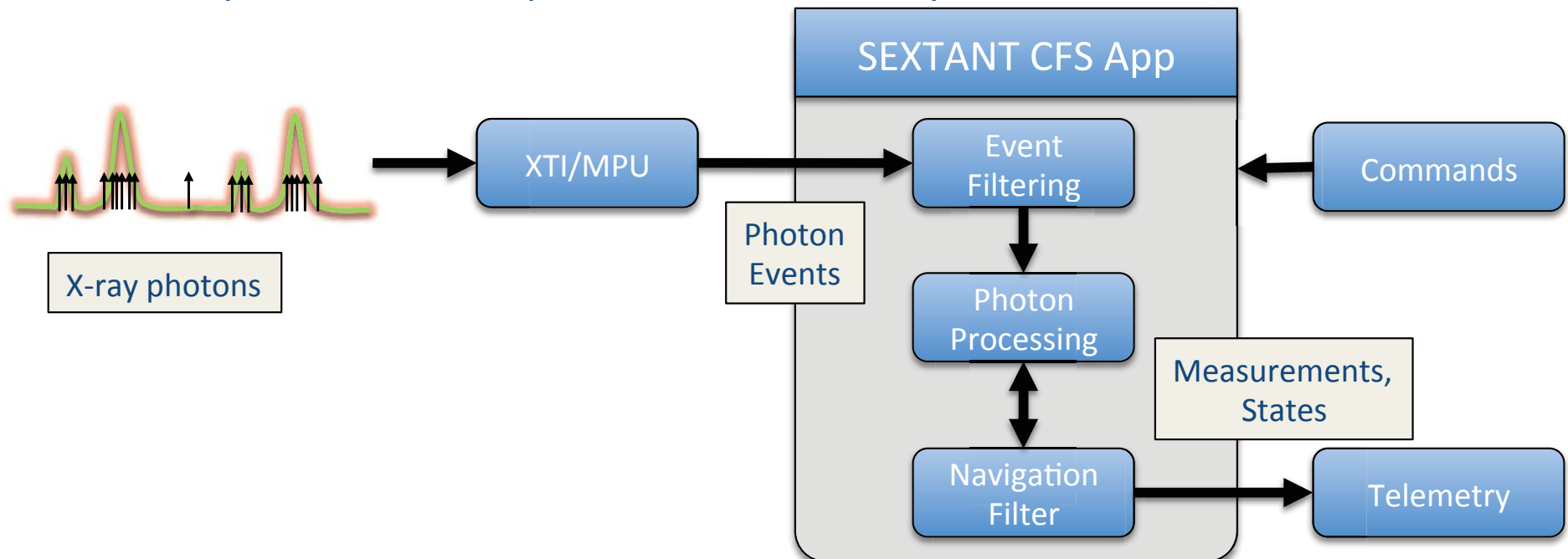


Stowed, deploying, and observing at ELC mounted location on ISS



SEXTANT Flight Software App

- XNAV Flight Software (XFSW) sequence flow:
 - XTI detects events from sequential pulsar observations, output via MPU
 - Pre-processing filters & buffers events until sufficient number from single pulsar collected
 - Batch process events to extract single measurement of phase, Doppler, count rates
 - Navigation algorithm (GEONS EKF) blends models of dynamics with measurement(s) to update spacecraft state estimate
- Ground system maintains pulsar almanac used by XFSW





SEXTANT Ground Testbed

Level 0 simulation

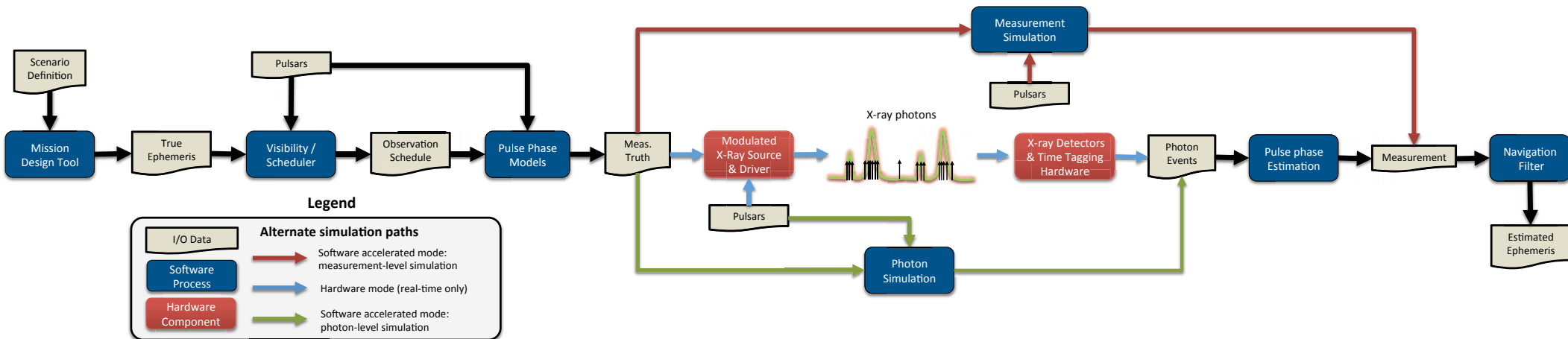
- Software only XNAV measurement simulation
- Useful for long term studies (deep space trajectories, etc)

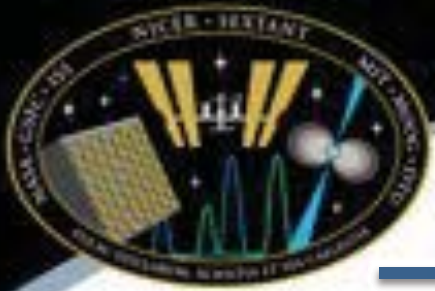
Level 1 simulation

- Software only photon event simulation
- Photon Processing algorithm implemented for measurement generation
- Primary mode of development for SEXTANT

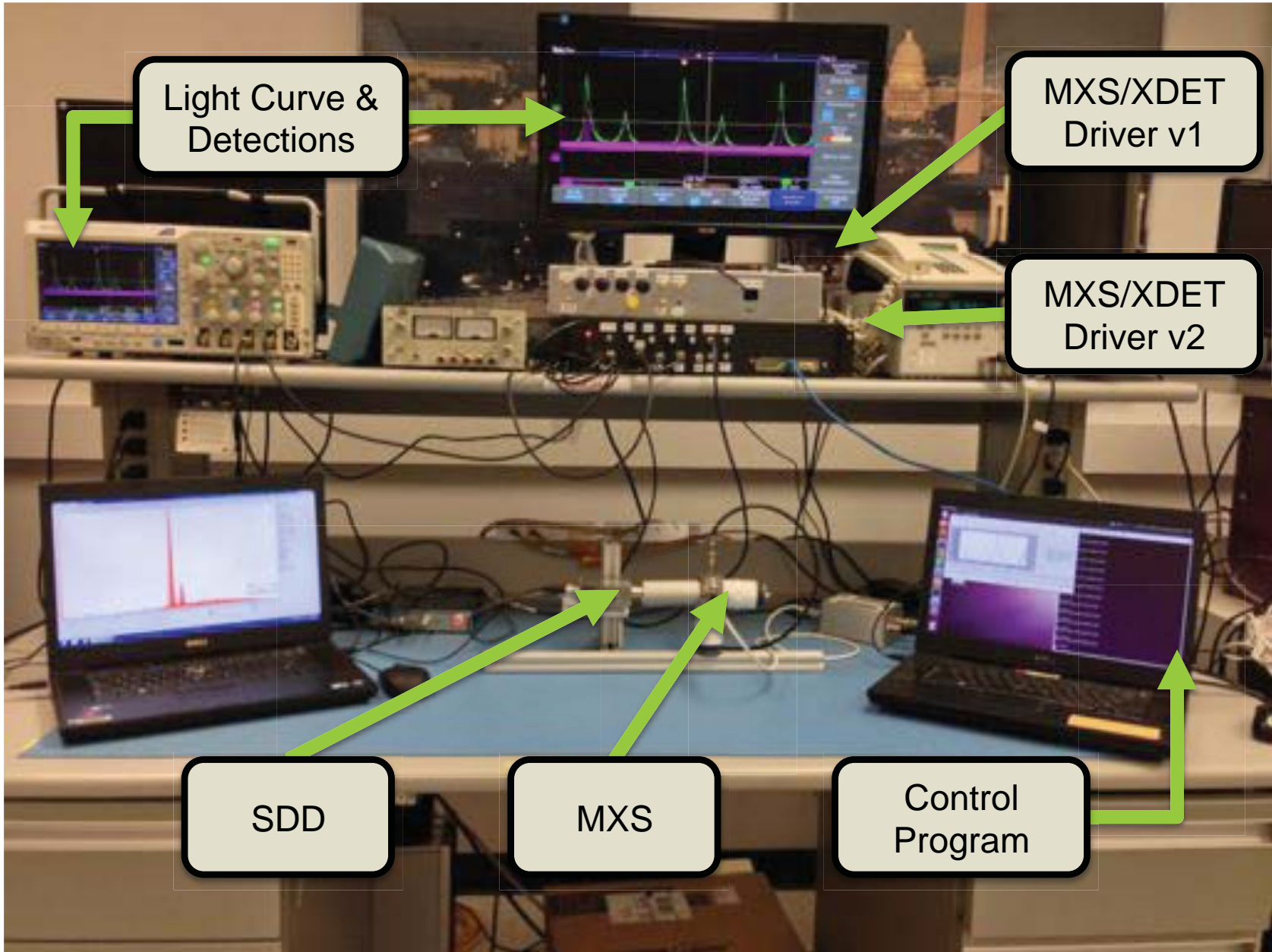
Level 2 simulation

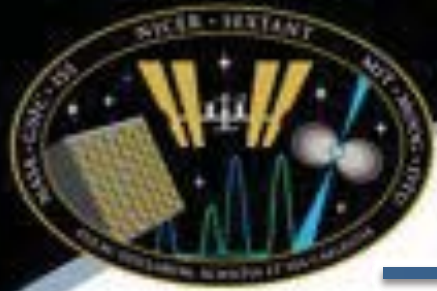
- Hardware-in-the-loop simulation
- *Test-as-you-fly*
- Use the Modulated X-ray source (MXS) to generate the photon events
- X-ray detector & electronics time-tag the photon events
- Useful for testing flight hardware





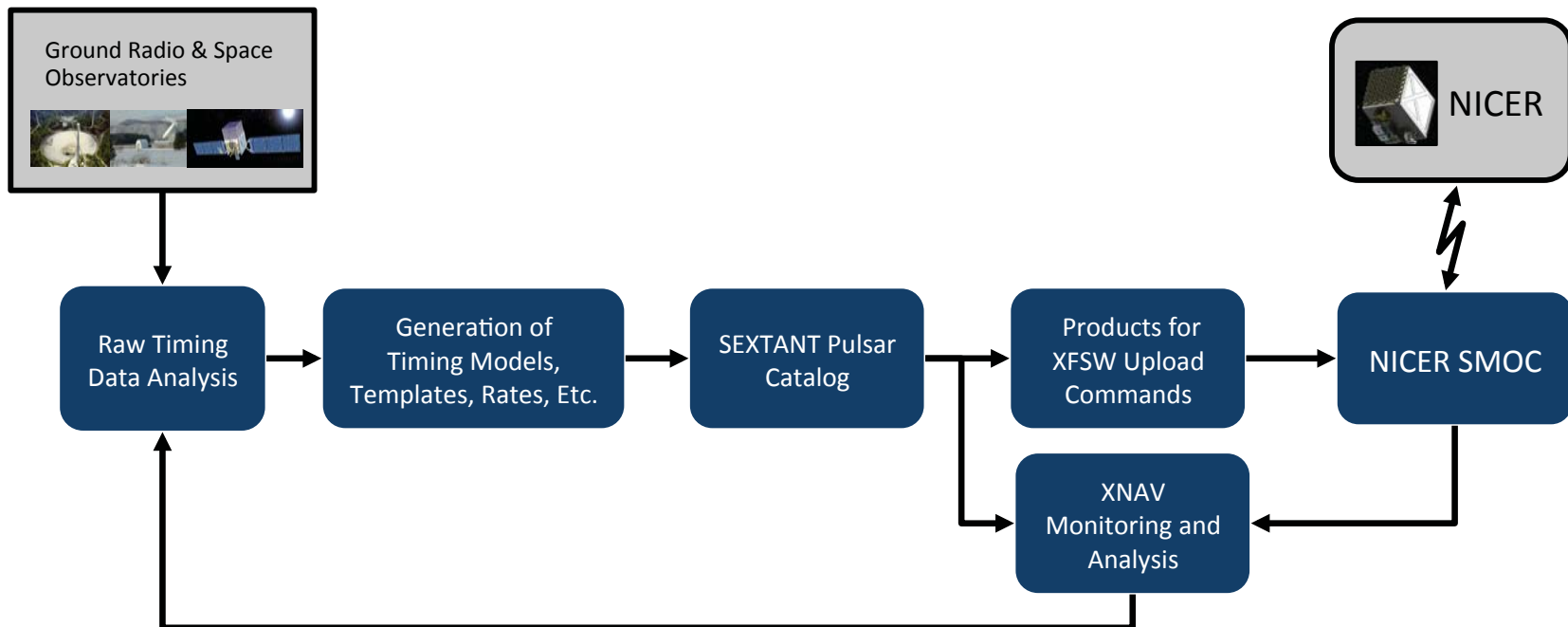
Goddard X-ray Laboratory Testbed (GXLT)

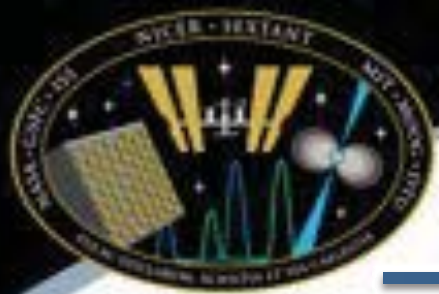




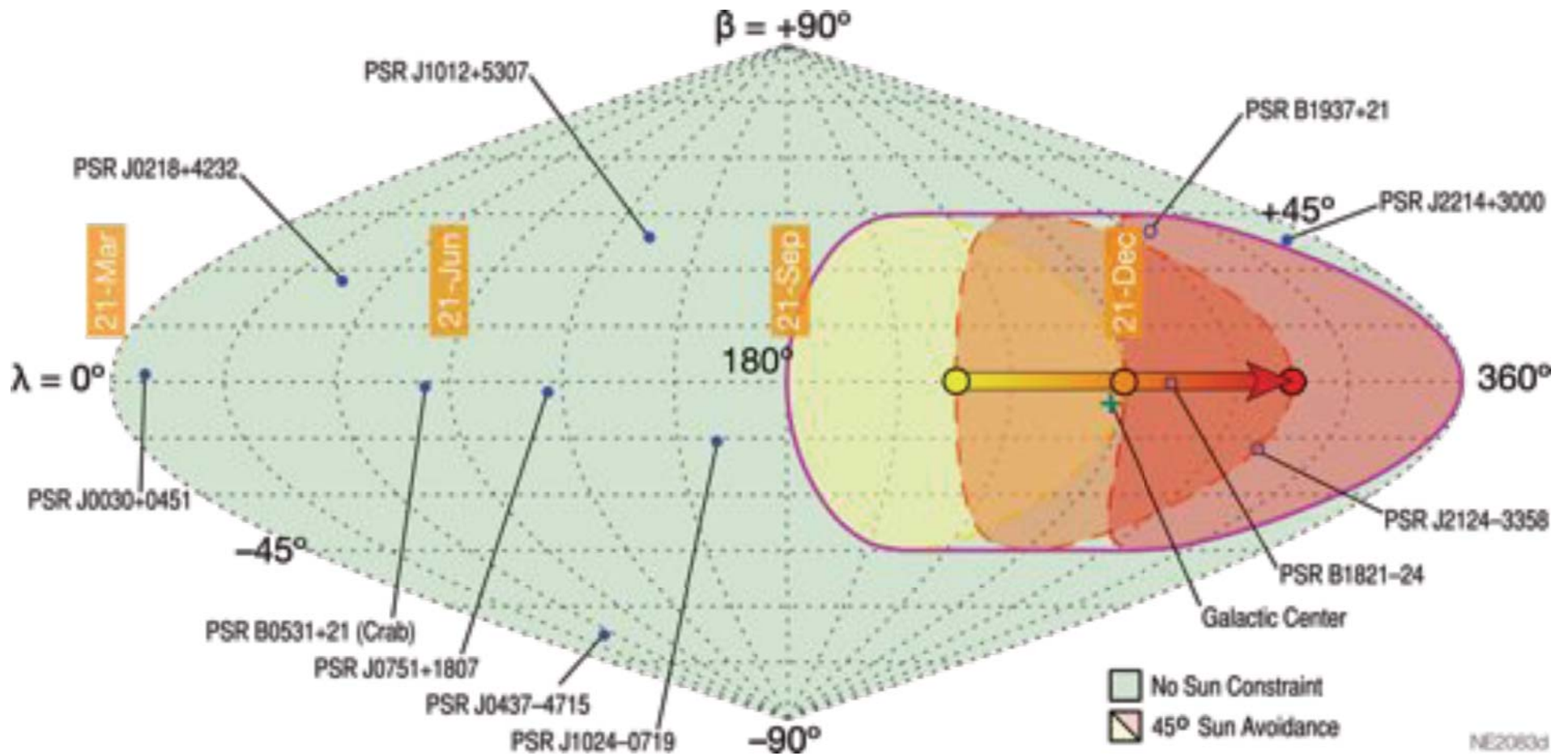
SEXTANT Ground System

- Generate and maintain the pulsar almanac
 - Timing models
 - Profile templates (light-curves)
- Maintain and update application
 - Pulsar upload tables
 - GEONS maintenance commands
- Monitor performance
 - Trending
 - Alerts
- Driven initially with radio observations
 - NICER data after sufficient data collected



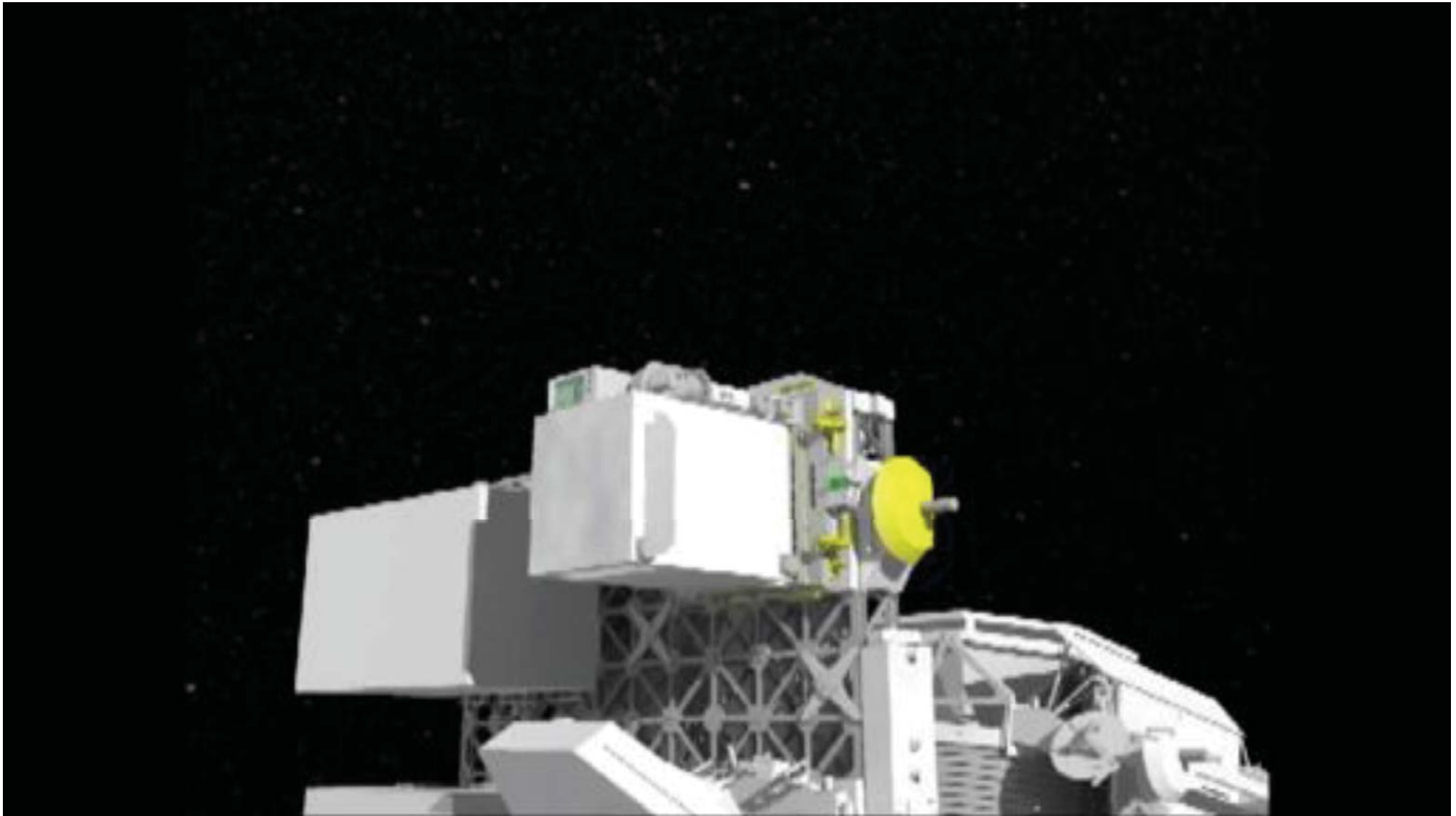


Concept of Operations (1/3)





Concept of Operations (2/3)





Concept of Operations (3/3)





Current Progress

- NICER in Phase C
- Successful review progress
 - SEXTANT Baseline Review Aug 2013
 - NICER PDR Dec 2013
 - SEXTANT CDR-EPR Aug 2014
 - GCD Continuation Review Aug 2014
 - NICER IFSW Aug 2014
 - NICER CDR Sep 2014
- Milestones
 - XFSW Build 0 (internal) Dec 2013
 - XFSW Build 1 Apr 2014
 - XFSW Build 1.1 (clean-up) May 2014
 - IFSW Build 1 integration & testing Jun 2014

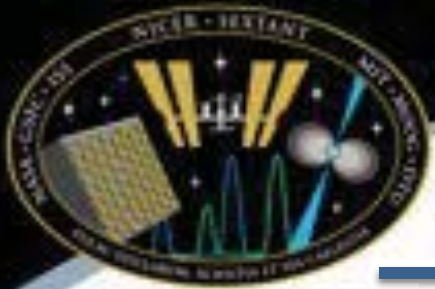


Summary & Future Work

- NICER/SEXTANT is an excellent partnership between science and technology (SMD & STMD)
- SEXTANT will be a:
 - First demonstration of real-time, on-board XNAV
 - Significant historical event enabled by ISS
 - Bridge between science & technology to connect with the public
- Near-term milestones
 - XFSW Build 2 Mar 2015
 - IFSW Build 2 testing
- NICER URL
 - <http://heasarc.gsfc.nasa.gov/docs/nicer/>



Backup



SEXTANT in NICER Flight Software Architecture

