NASA Station Explorer for X-ray Timing and Navigation Technology (SEXTANT) Mission Operations Architecture

Wayne H. Yu[†], Sean R. Semper[†], Jason W. Mitchell[†], Luke B. Winternitz[†], Munther A. Hassouneh[†], Samuel R. Price[†], Paul S. Ray[‡], Kent S. Wood[#], Keith C. Gendreau[†], Zaven Arzoumanian[†]

[†] *NASA Goddard Space Flight Center*

[‡] *U.S. Naval Research Laboratory*

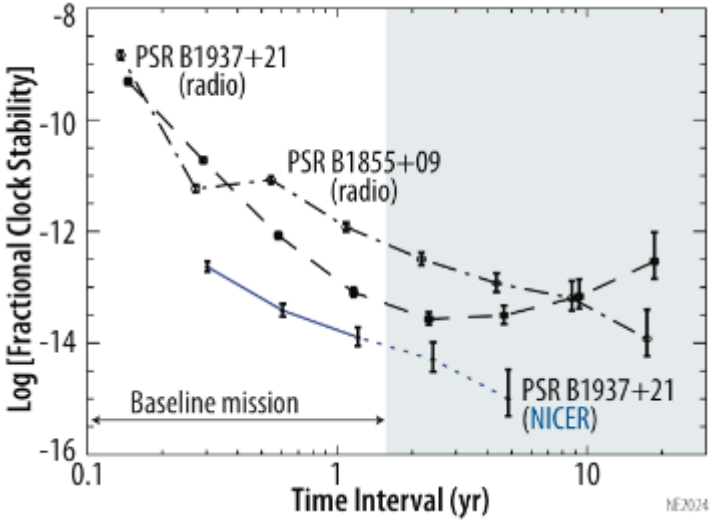
[#] *Praxis Inc., resident at Naval Research Laboratory*

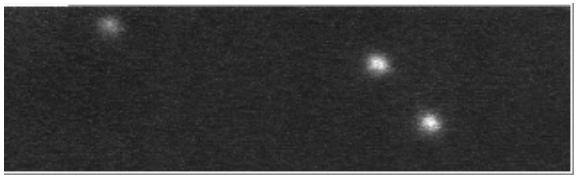
70th International Astronautical Congress

Washington, D.C.
October 23rd, 2019

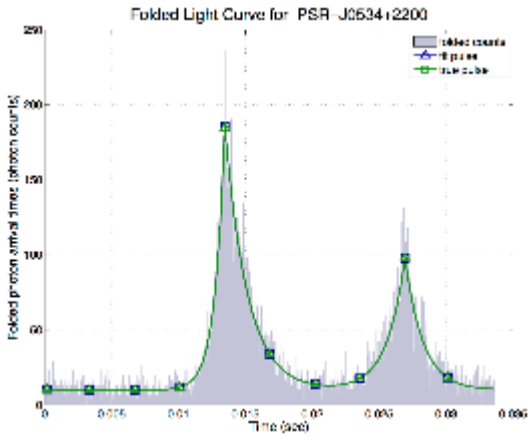
X-ray Pulsar Navigation (XNAV)

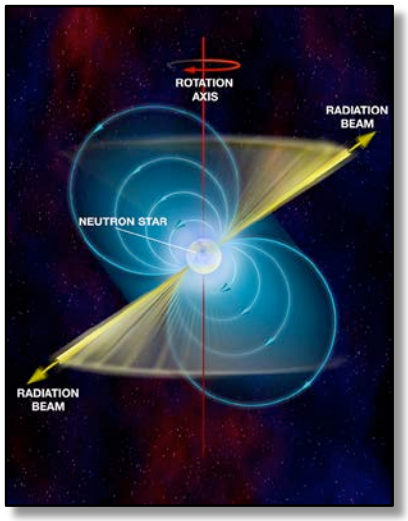
- Millisecond pulsars (MSPs): rapidly rotating neutron stars that pulsate across electromagnetic spectrum
- Some MSPs rival atomic clock stability at long time-scales
  - Predict pulse arrival phase with great accuracy at any reference point in the Solar System via pulsar timing model on a spacecraft
  - Compare observed phase to prediction for navigation information
- Why X-rays?
  - Many stable MSPs conveniently detectable in (soft) X-ray band
  - X-rays immune to interstellar dispersion thought to limit radio pulsar timing models
  - Highly directional compact detectors possible
- **Main Challenge: *MSPs are very faint!***





Crab Pulsar (1/3 speed), Cambridge University, Lucky Image Group





https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20190001154.pdf

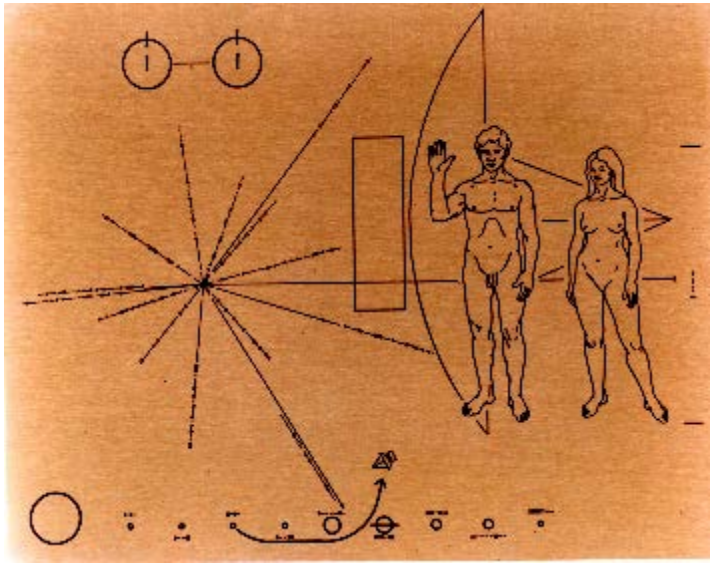
X-ray Pulsar Navigation (XNAV)

Applications

- XNAV can provide autonomous navigation and timing that is of uniform quality throughout the solar system
  - Is enabling technology for very deep space missions
  - Provides backup autonomous navigation for crewed missions
  - Augments Deep Space Network (DSN) or op-nav techniques
  - Allows autonomous navigation while occulted, e.g., behind Sun

History

- Pulsars were discovered in 1967 and immediately recognized as a potential tool for Galactic navigation
- US Naval Research Laboratory (NRL) (1999-2000)
  - Unconventional Stellar Aspect (USA) Experiment
- DARPA XNAV, XTIM Projects (2005-2006, 2009-2012)
- Significant body of research (international interest, academic research, several Ph.D. dissertations, etc.)
- ***NICER/SEXTANT successfully demonstrates real-time, onboard, autonomous XNAV* (Nov 2017)**



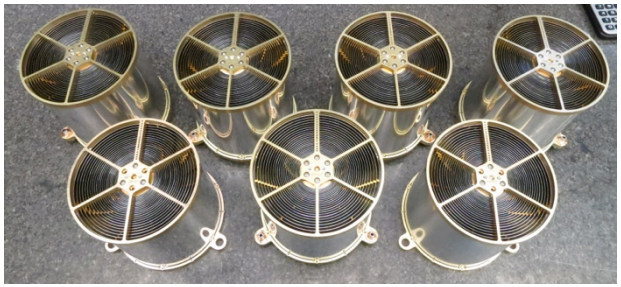
Pioneer plaque (Pioneer 10,11 1972-73) with pulsar periods and relative distances to our Sun

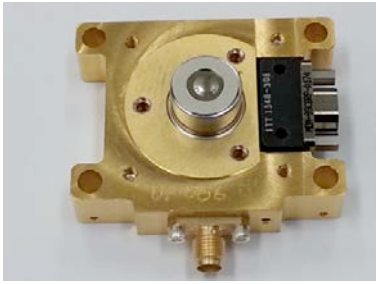
Credit: NASA Ames

https://solarsystem.nasa.gov/resources/706/pioneer-plaque/

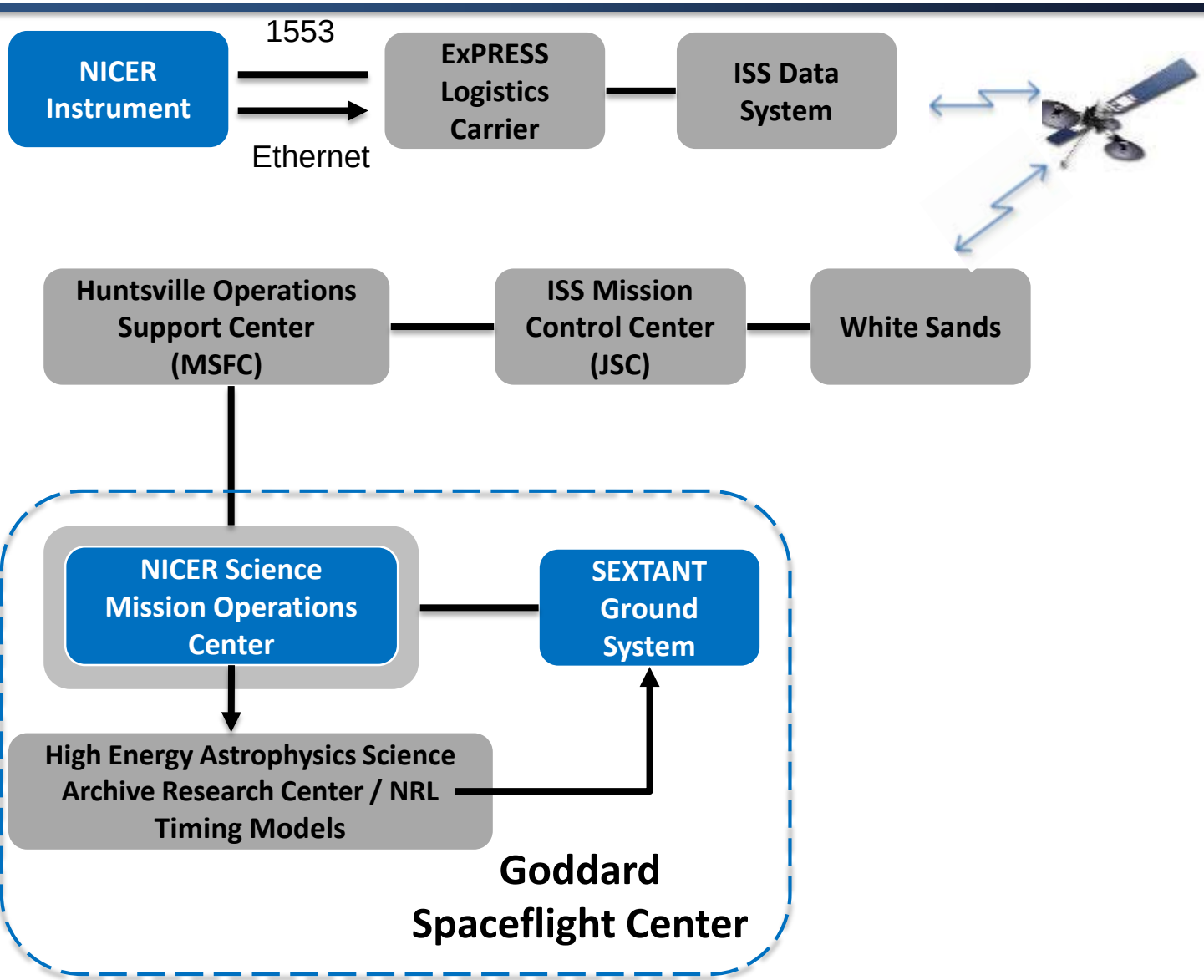
NICER/SEXTANT Overview

- Launched on June 3, 2017 on Space-X CRS-11 to ISS
- Neutron-star Interior Composition Explorer (NICER)
  - Fundamental investigation of ultra-dense matter: structure, dynamics, & energetics
  - Nearly ideal XNAV detector combination: low-background, large effective collecting area, precise timing, scalability, and low-cost
  - Assembly of 56 X-ray concentrators and detectors, ~1800 cm^2 effective collecting area in soft X-ray band
  - Scalable design, e.g., reduce to 1,4,10, etc. concentrators
- SEXTANT – Successful demonstration results reported in Mitchell (2018) and Winternitz (2018)

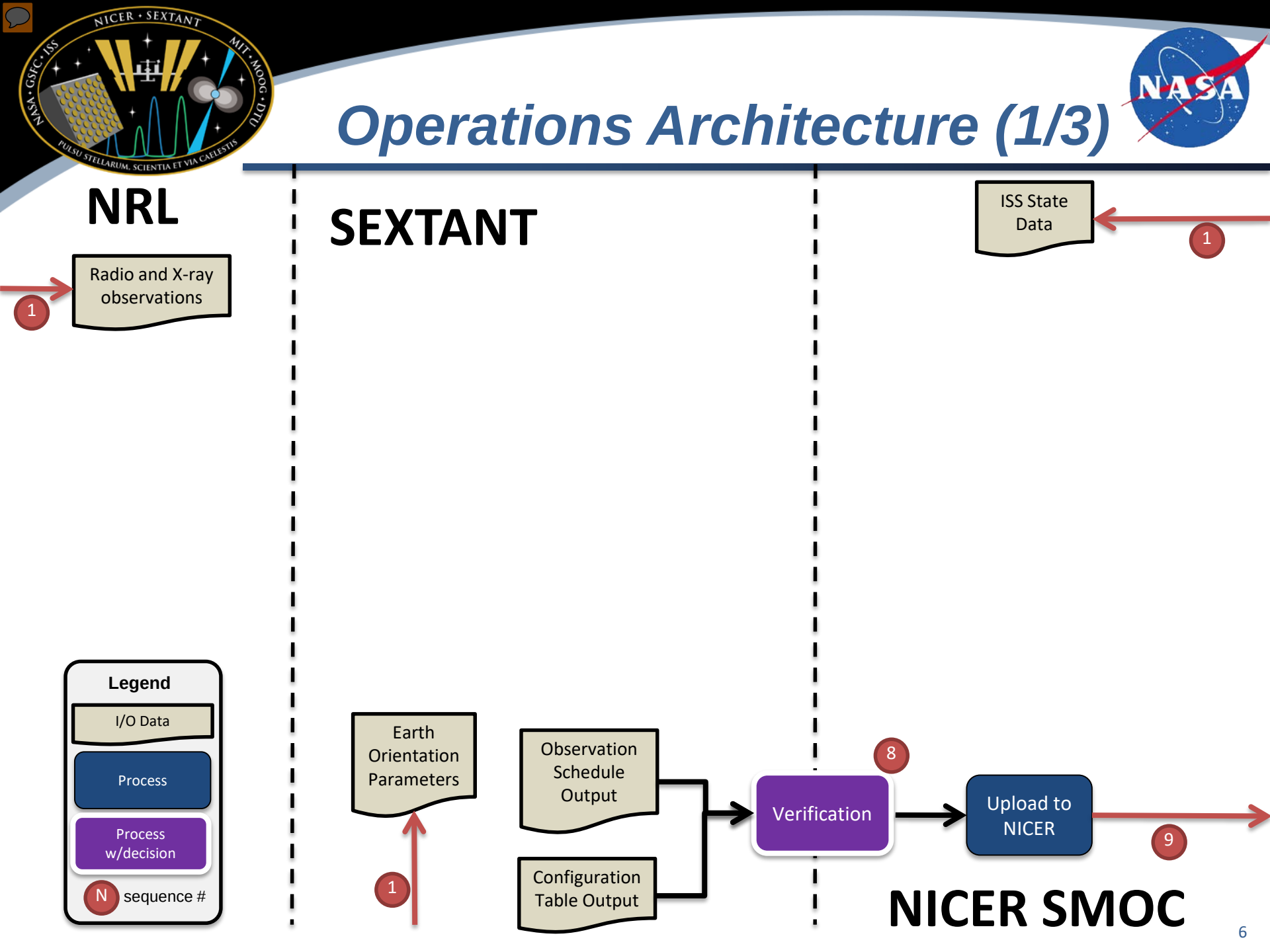




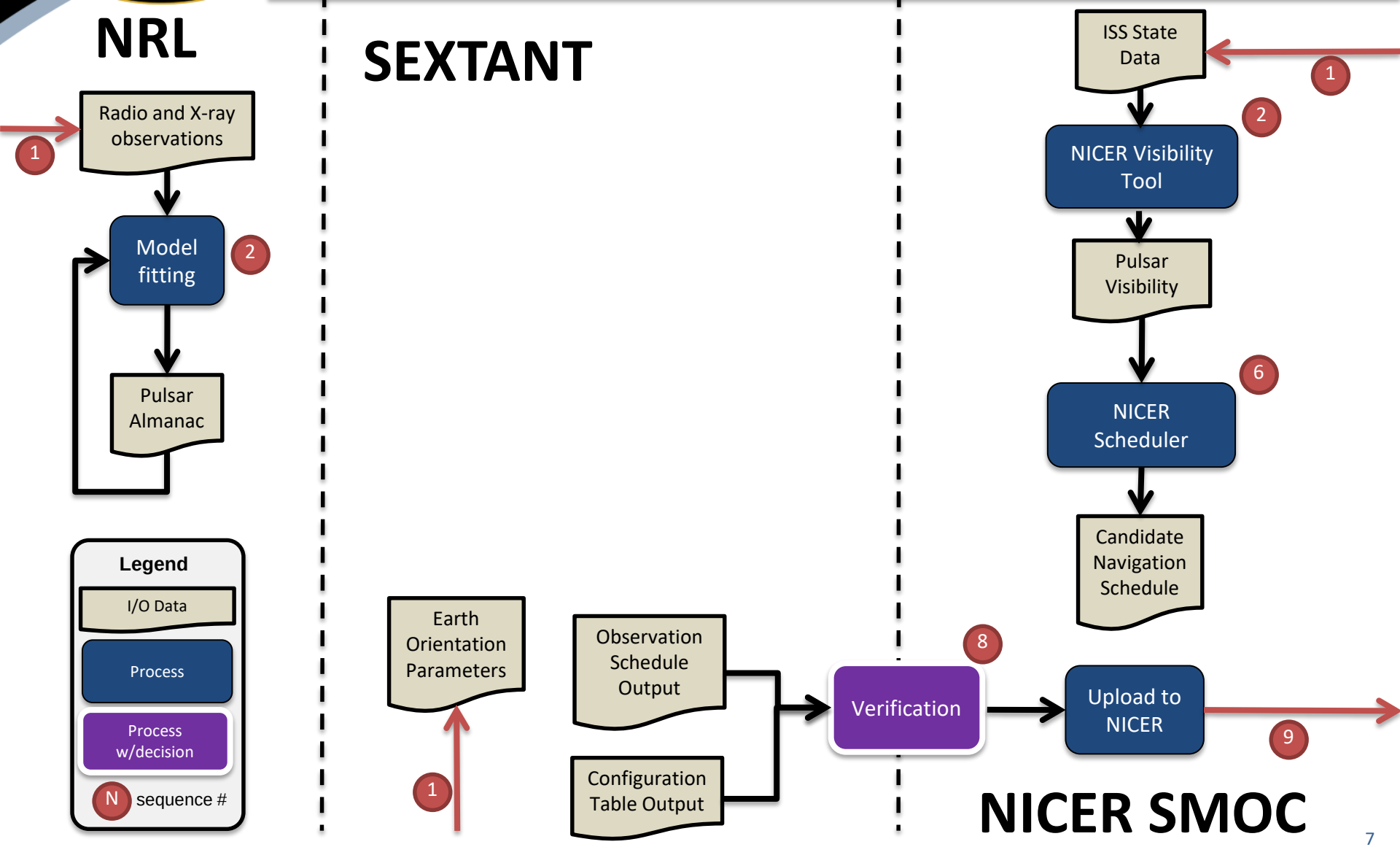
Operations Overview



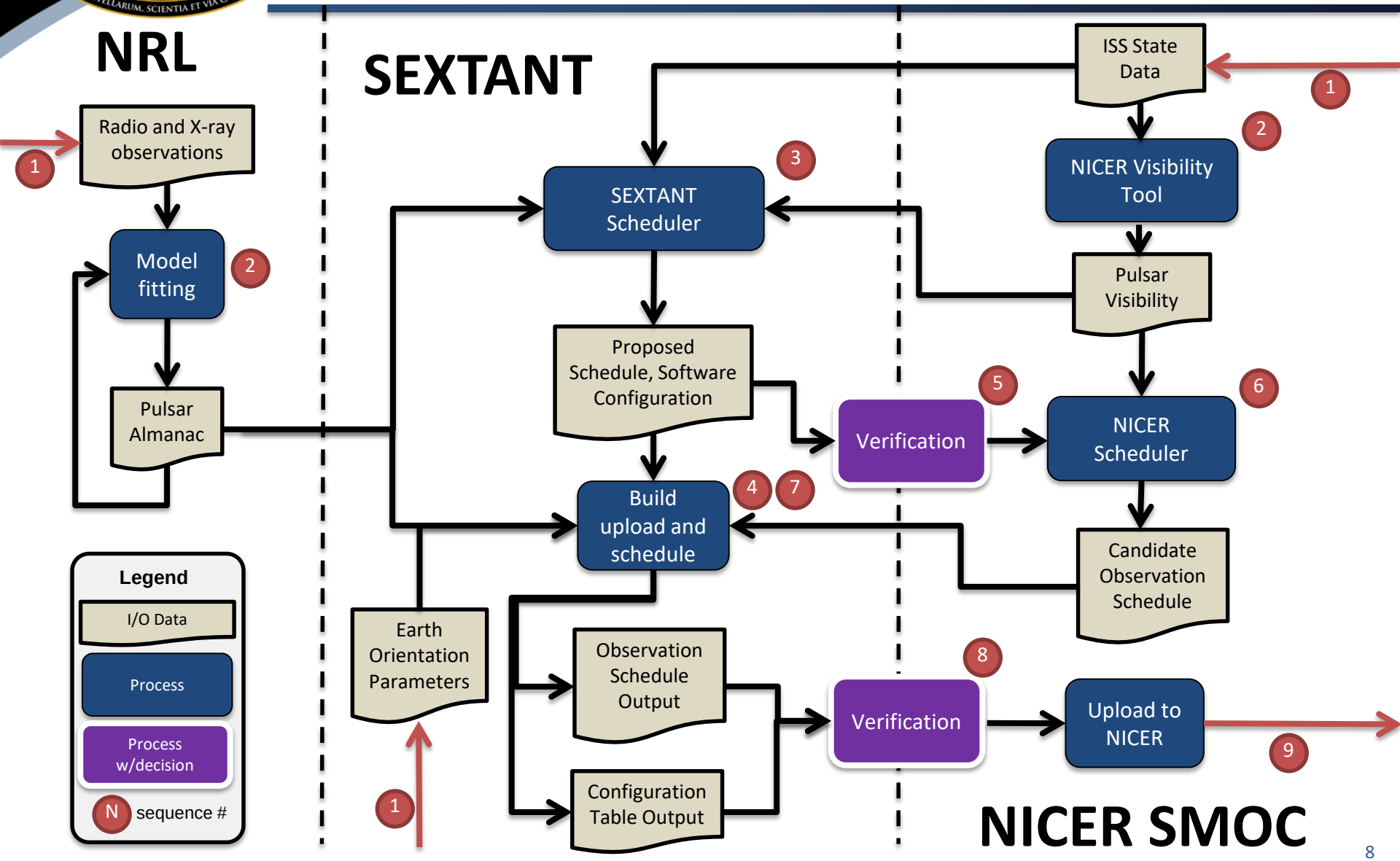
Operations Architecture (1/3)



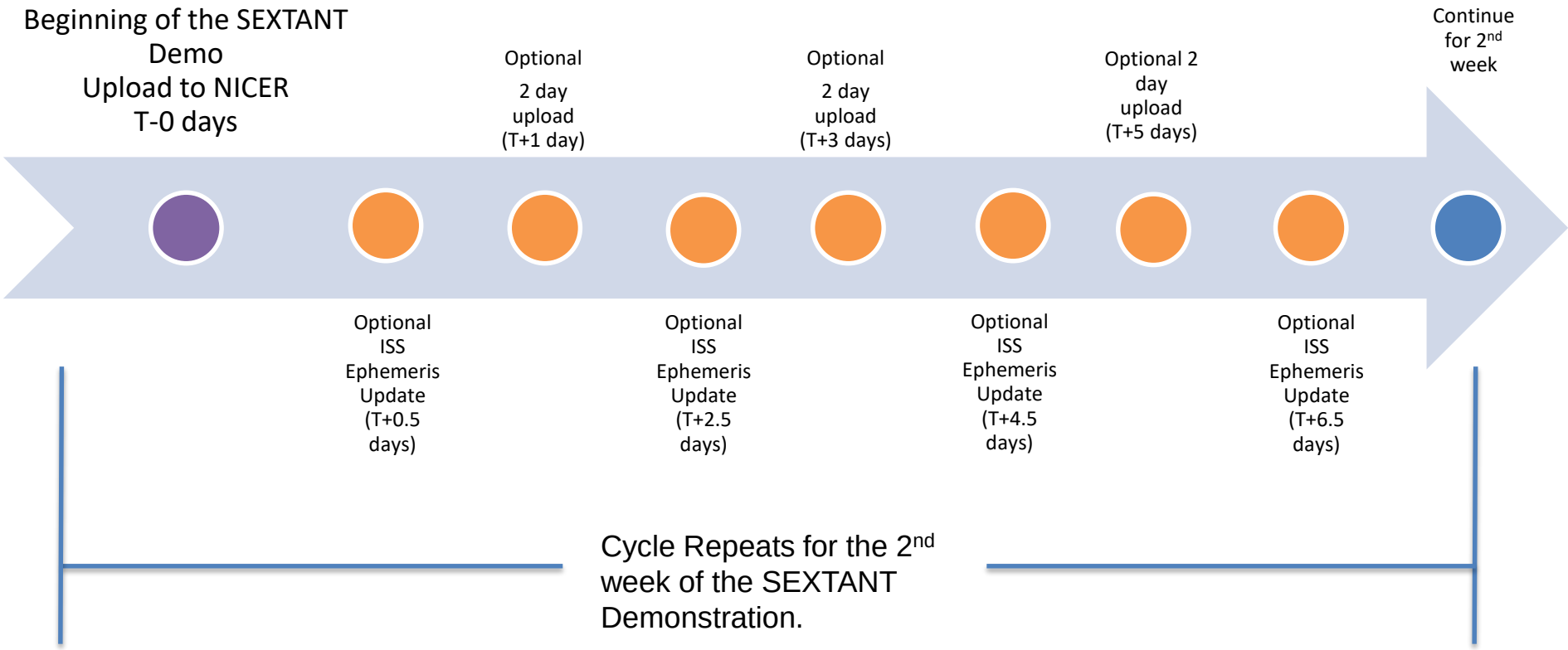
Operations Architecture (2/3)



Operations Architecture (3/3)

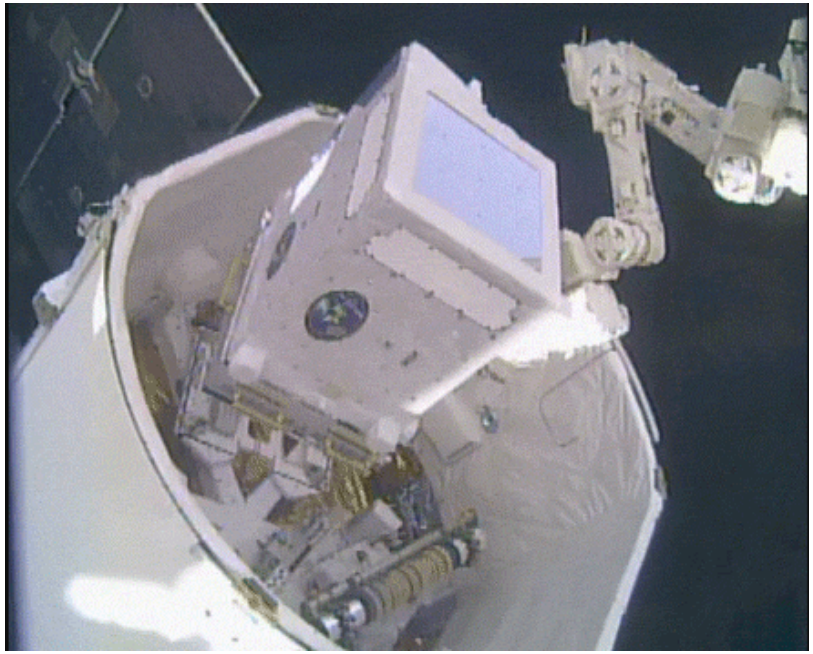


Concept of Operations



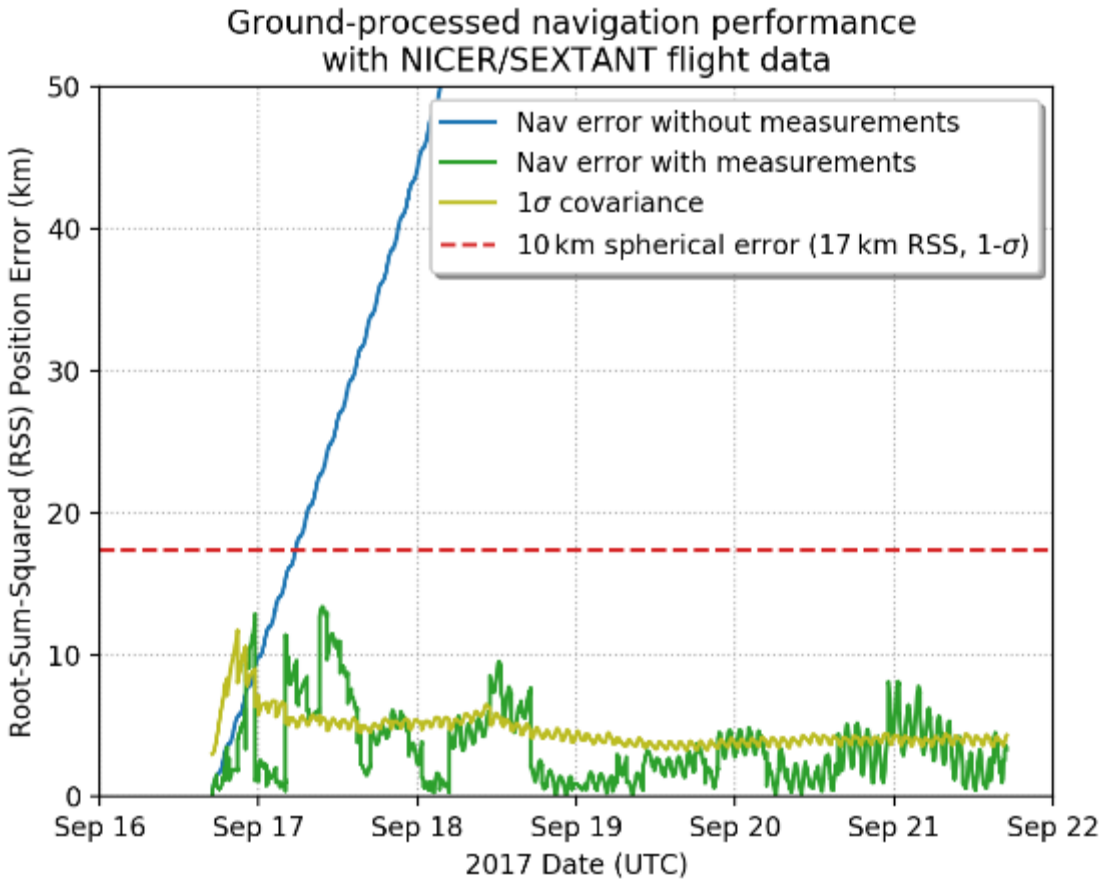
On Orbit Demo Preparation

Date	ISS Critical Operations Event
6/5/2017	SpaceX Dragon (NICER payload) docks
6/16/2017	Progress 67 resupply ship docks
7/3/2017	SpaceX Dragon capsule departs
7/20/2017	Progress 66 departs
7/28/2017	Soyuz MS-05 docks
8/16/2017	SpaceX Dragon docks
9/17/2017	SpaceX Dragon departs
9/27/2017	ISS orbital reboost
10/16/2017	Progress 68 docks

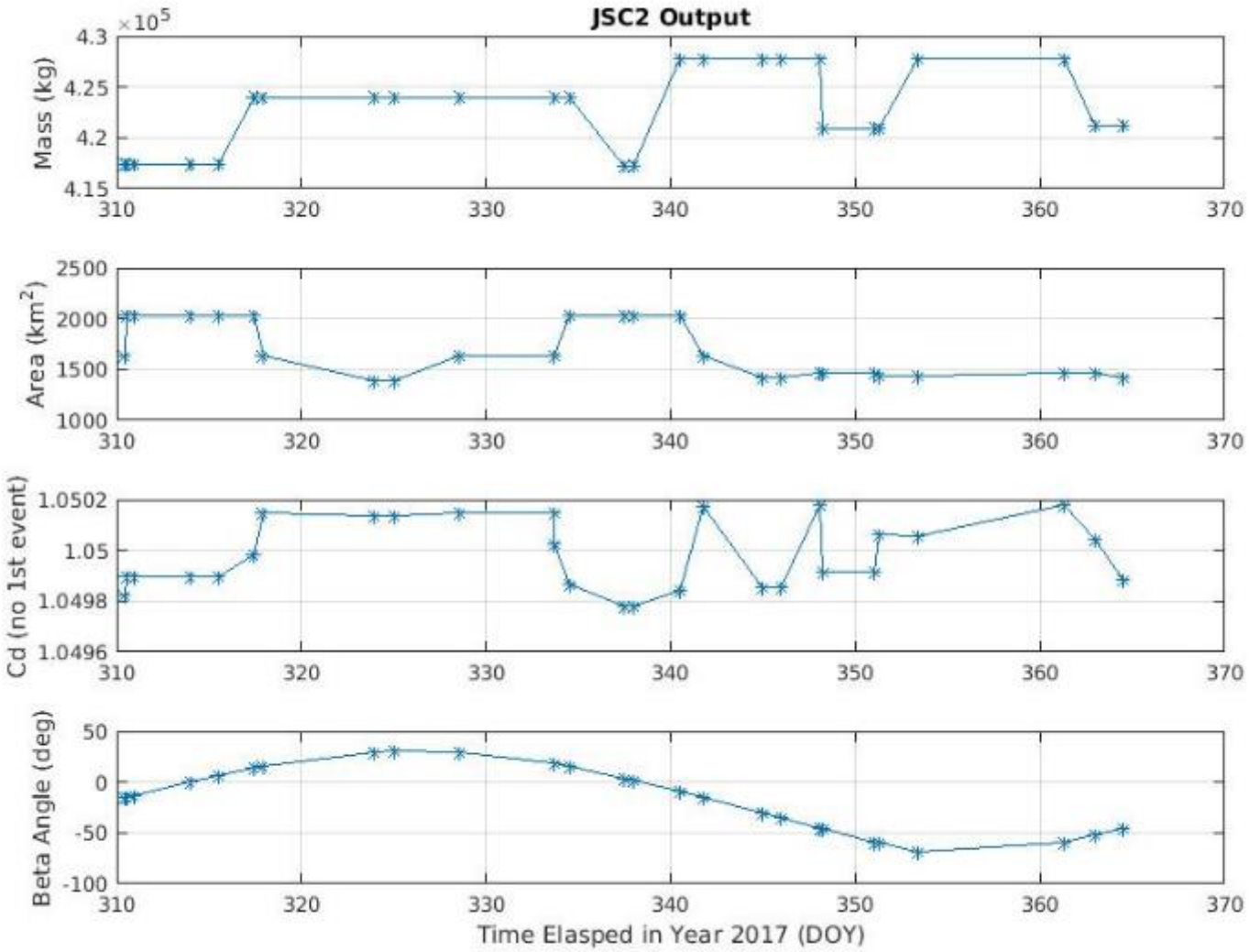


https://heasarc.gsfc.nasa.gov/docs/nicer/nicer_gallery.html

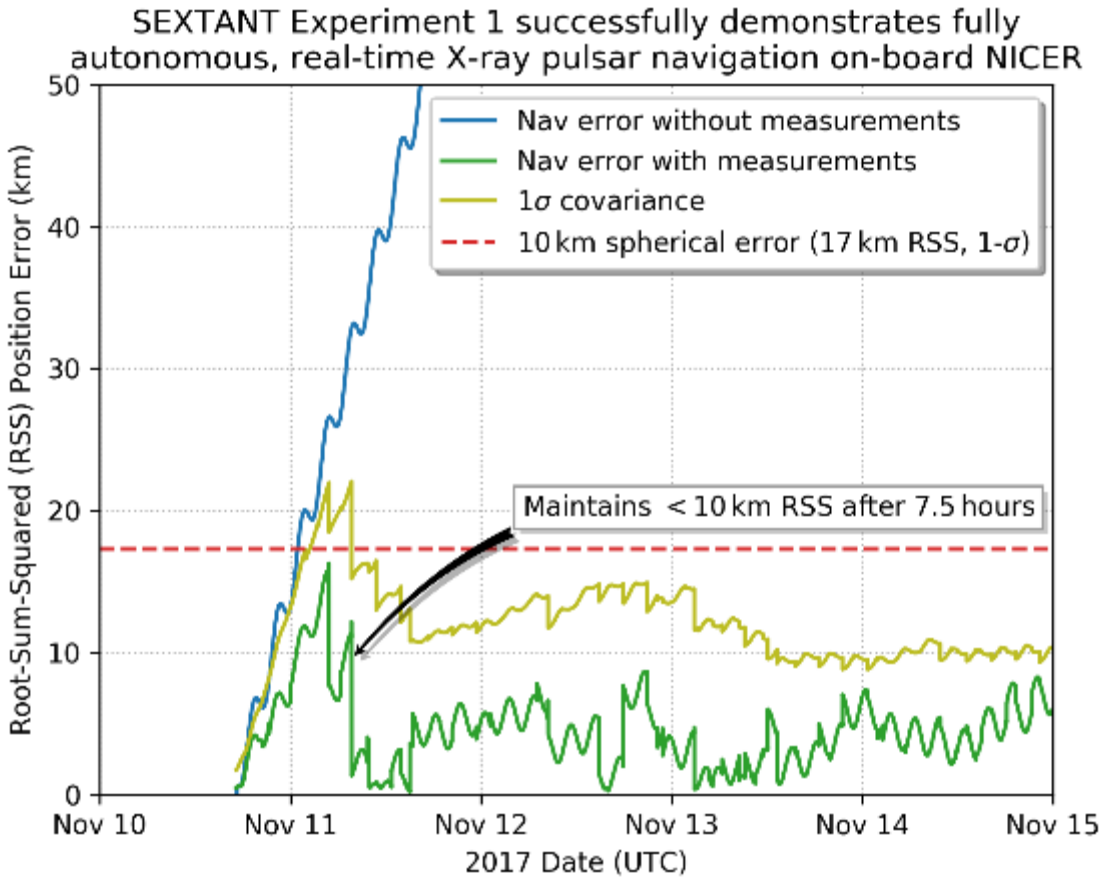
On Orbit Demo Preparation



On Orbit Demo Preparation



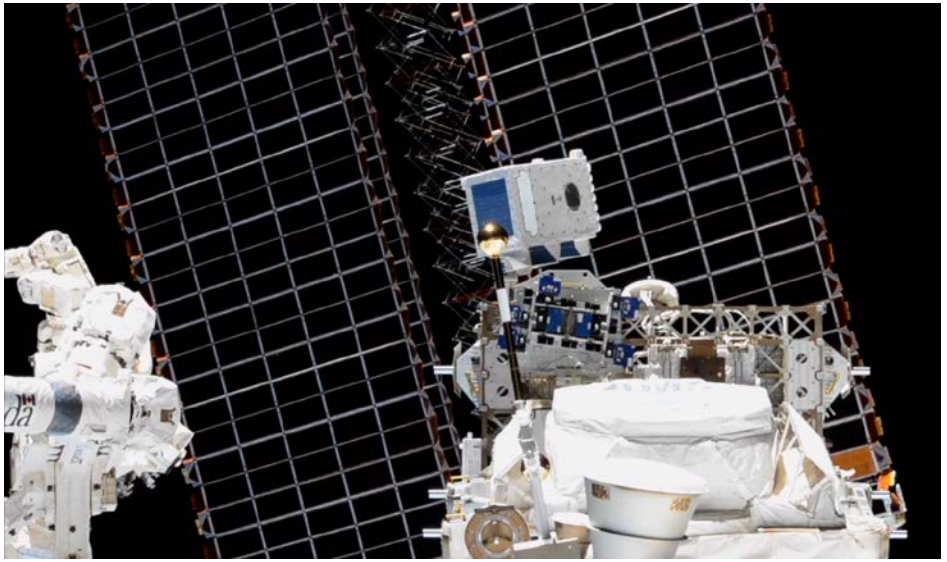
XNAV Demonstration



XNAV Demonstration

Conclusions & Future Work

- SEXTANT demonstrated XNAV on board and in real time on the ISS in 2017
  - 10 km settled RSS in 7.5 hours with < 1 km point solutions
  - 33% duty cycle of observations on 4 pulsar targets
- Illustrated the SEXTANT Ground System used to execute the demonstration
  - Integrated with the NICER instrument/ops team, ISS JSC and MSFC payload operation teams
  - Performs navigation filtering while simultaneously supporting NICER science and ISS mission operations



https://heasarc.gsfc.nasa.gov/docs/nicer/nicer_gallery.html