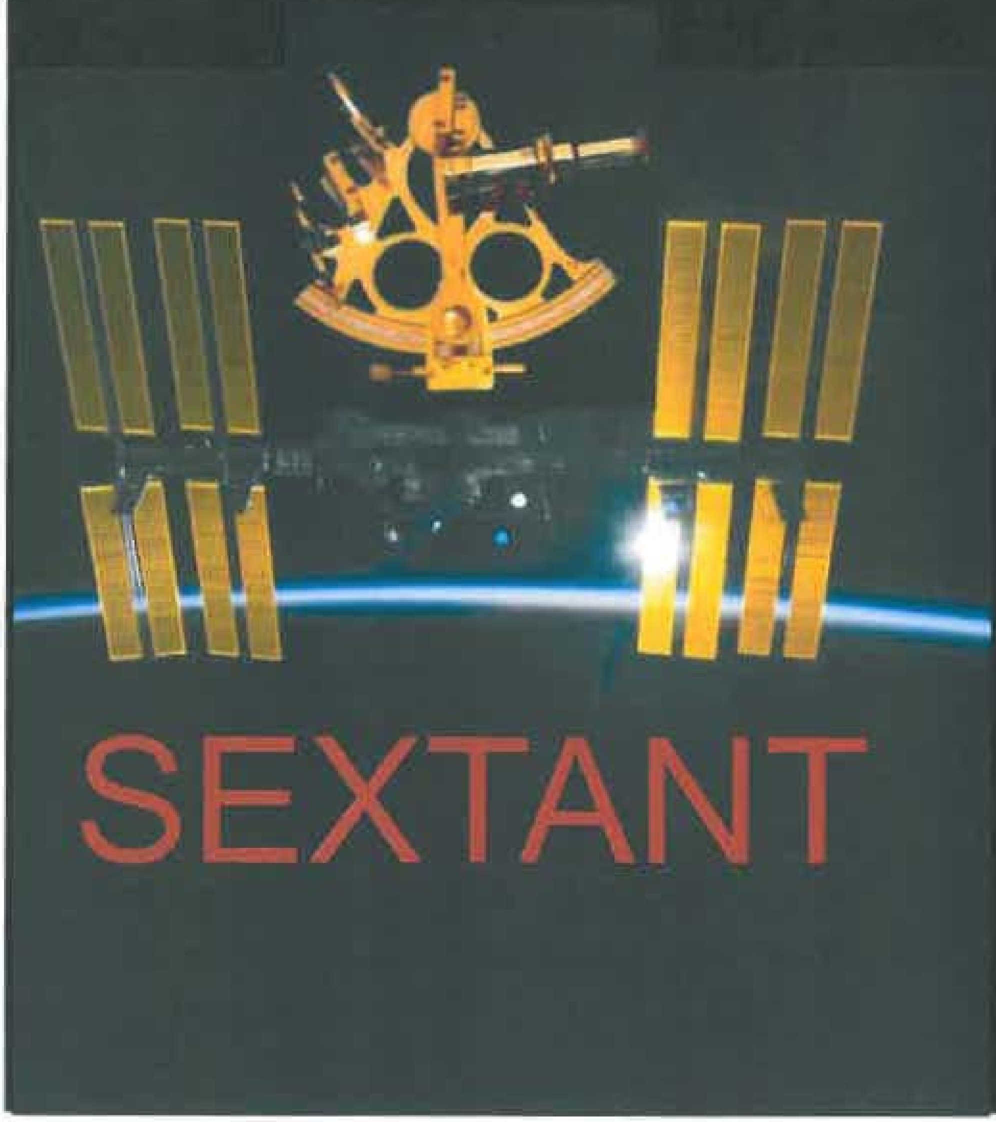


NICER:
Neutron Star Interior Composition ExploreR and SEXTANT

Keith Gendreau
NASA/GSFC
301-286-6188

NICER Mission Overview

Astrophysics on the International Space Station:
Understanding ultra-dense matter through soft X-ray timing

- ***Science:*** A proposed International Space Station (ISS) payload dedicated to the study of ***neutron stars***—a fundamental investigation of extremes in gravity, material density, and electromagnetic fields.
- ***Spacecraft:*** Hosted on the ISS Express Logistics Carrier
- ***Launch***: CBE= August 2016 by JAXA HIIB/HTV or Space-X Falcon 9/Dragon
- ***Duration:*** 18 (min.12) months
- ***Team:*** NASA GSFC, MIT. Science co-Is from USRA, UMCP, UMBC, NRL, University of Arizona, McGill, SUNY, MSU, F&M, NRAO, UNAM.

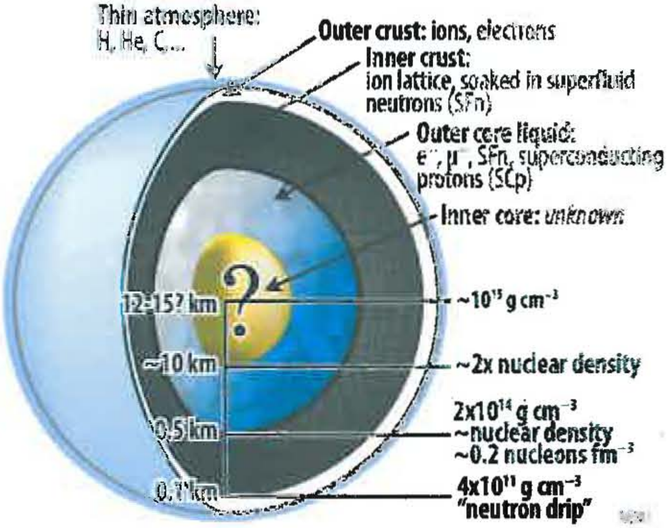
NICER: The Science Argument

NICER Science Objectives

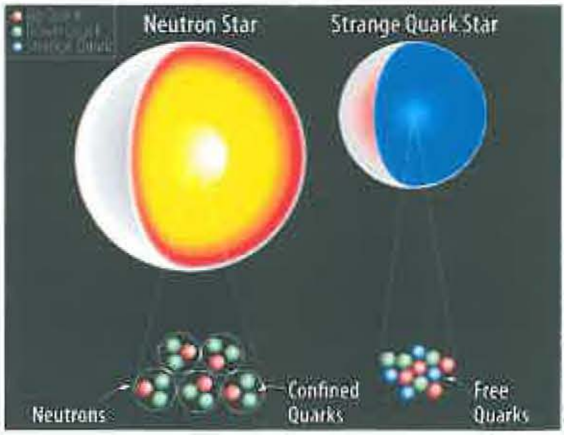
Neutron stars—Unique environments in which all four fundamental forces of Nature are simultaneously important.

- To address NASA and National Academy of Sciences strategic questions
- To resolve the nature of ultradense matter at the threshold of collapse to a black hole
- To reveal interior composition, dynamic processes, and radiation mechanisms of neutron stars.

Credit: M. Garlick



Objective	Measurements
Structure—Reveal the nature of matter in the interiors of neutron stars.	Neutron star radii to ±5%. Cooling timescales.
Dynamics—Uncover the physics responsible for the dynamic behavior of neutron stars.	Stability of pulsars as clocks. Properties of outbursts, oscillations, and precession.
Energetics—Determine how energy is extracted from neutron stars.	Intrinsic radiation patterns, spectra, and luminosities.



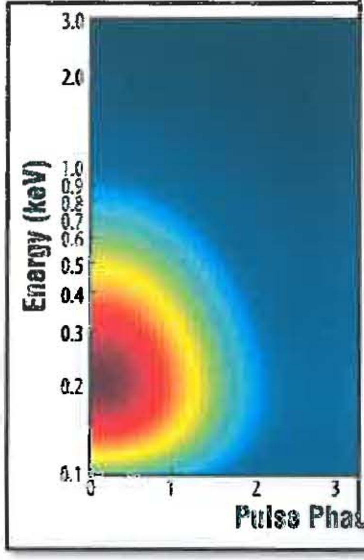
Credit: CXC/M. Weiss

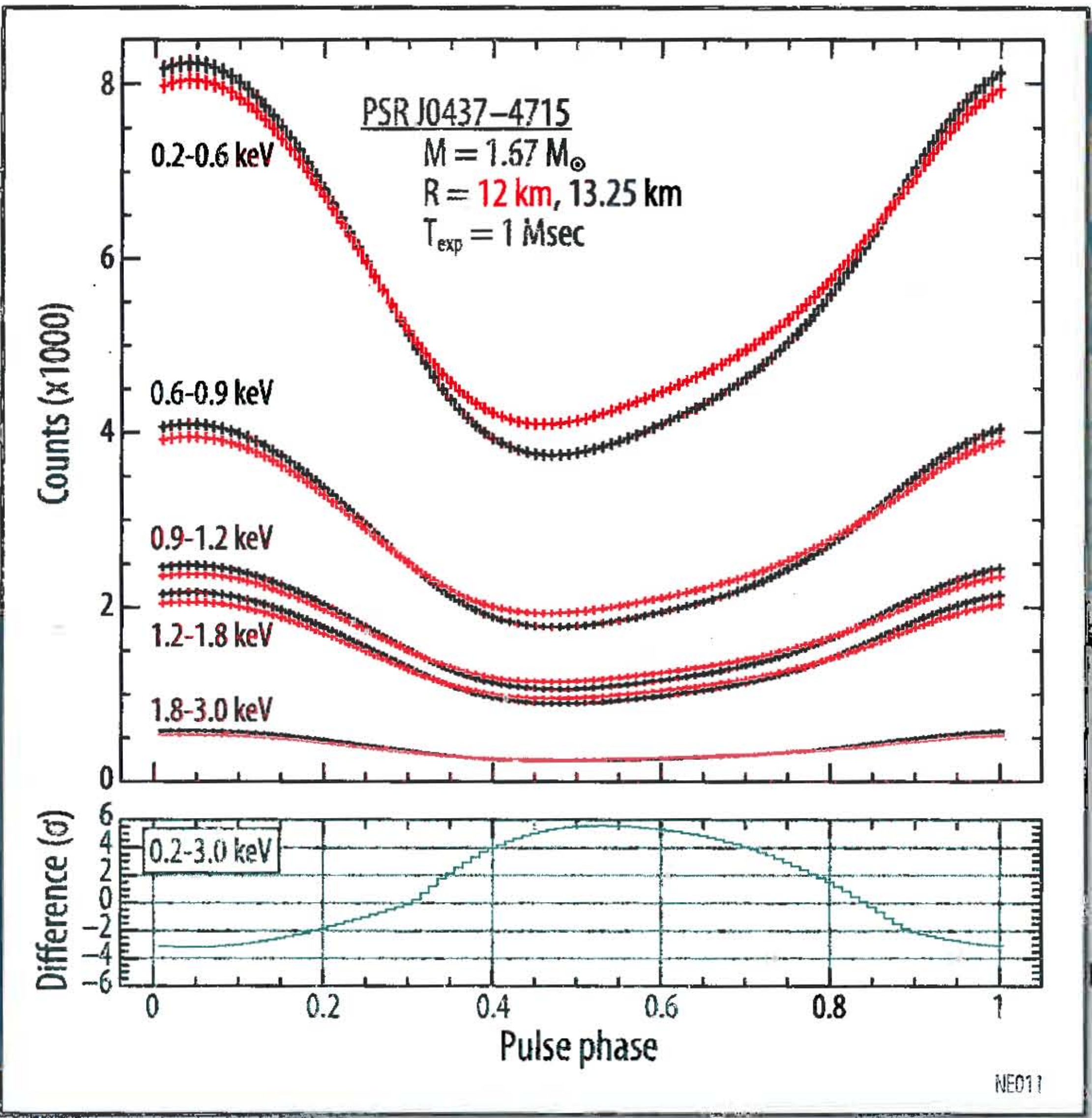
NICER Science Measurements

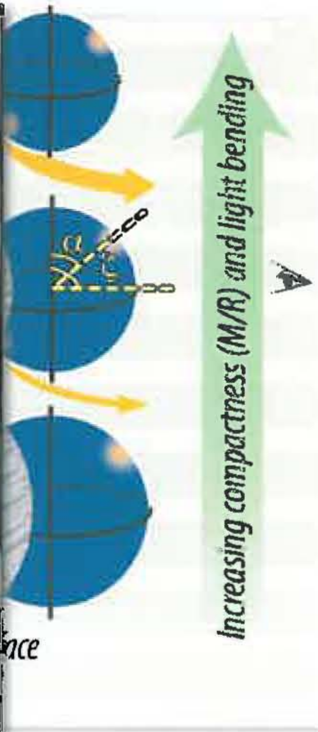
Structure through lightcurve modeling, long-term timing, and pulsation searches

Lightcurve mo

Shape of mod
constrains co
ness (*M*/*R*) an
viewing geom







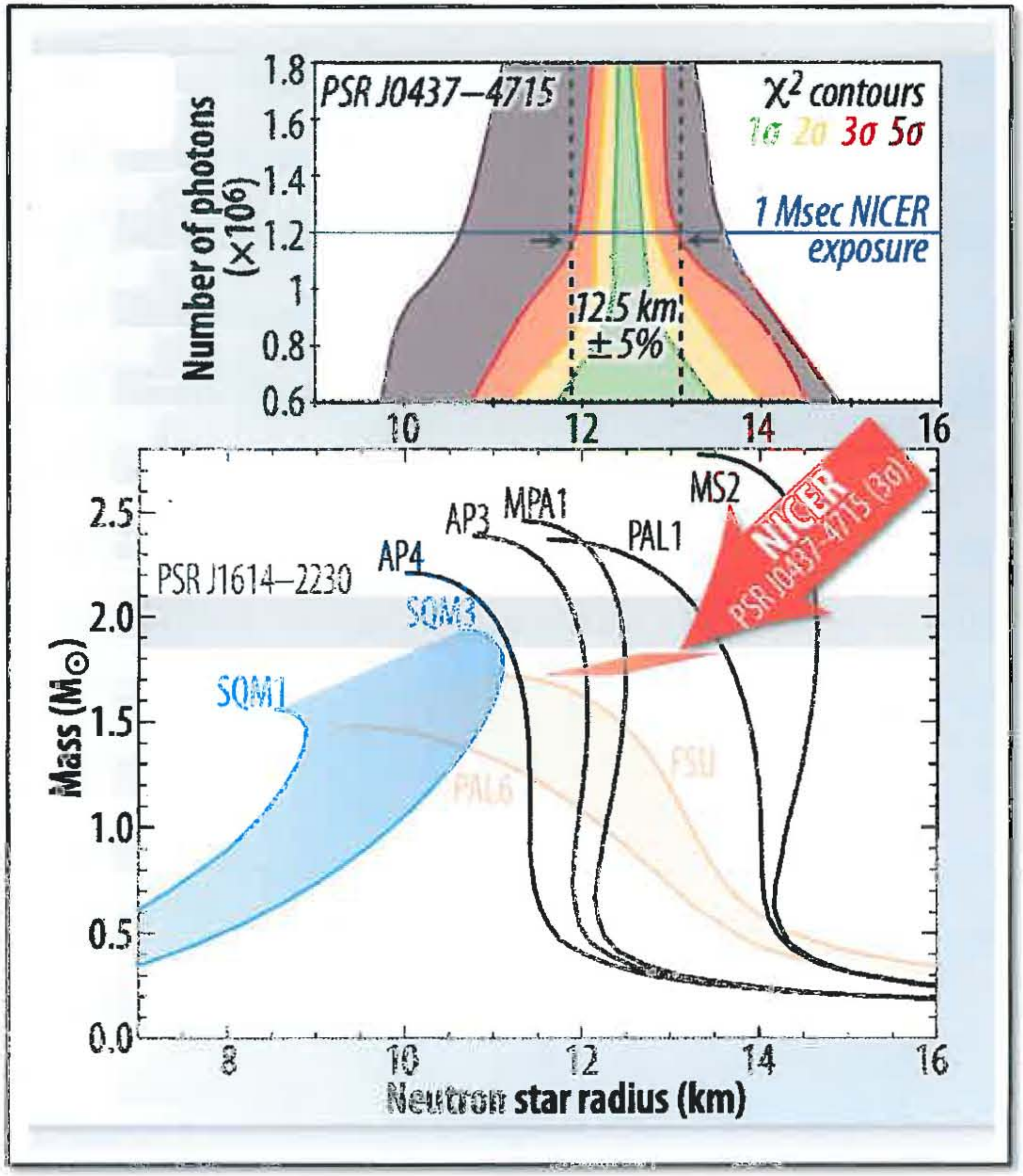
romises

NICER Science Measurements

Structure through lightcurve modeling, long-term timing, and pulsation searches

Simulations demonstrate how well an assumed neutron star radius can be recovered.

The resulting allowed regions in the *M-R* plane rule out proposed families of neutron star equations of state. The best mass measurements alone can't distinguish among competing models.

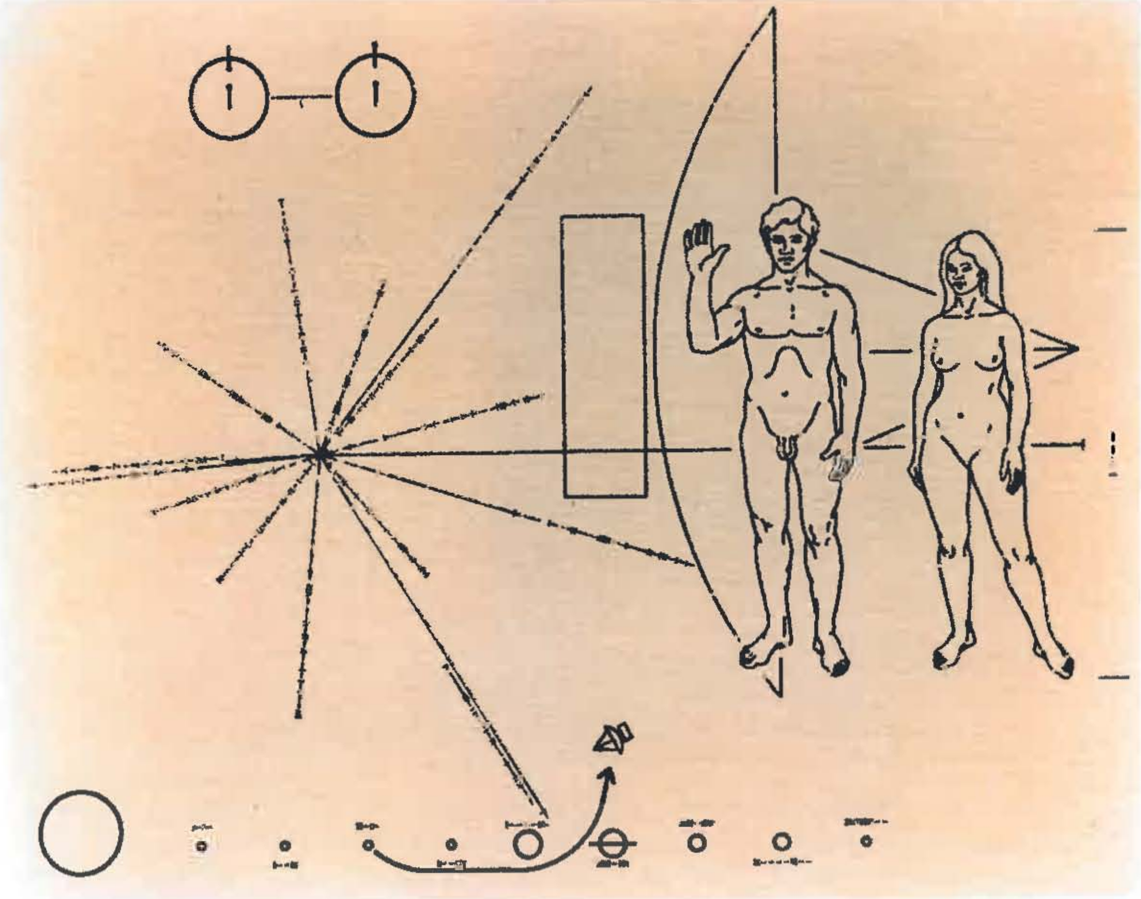


The Technology Demonstration Argument: XNAV and Pulsar Based Navigation

Pioneer Plaque: Flown on the Pioneer 10 Spacecraft

Pulsars were discovered in 1967 and immediately were recognized as a tool for Galactic navigation.

A map showing where the Solar system is relative to the known pulsars at the time.

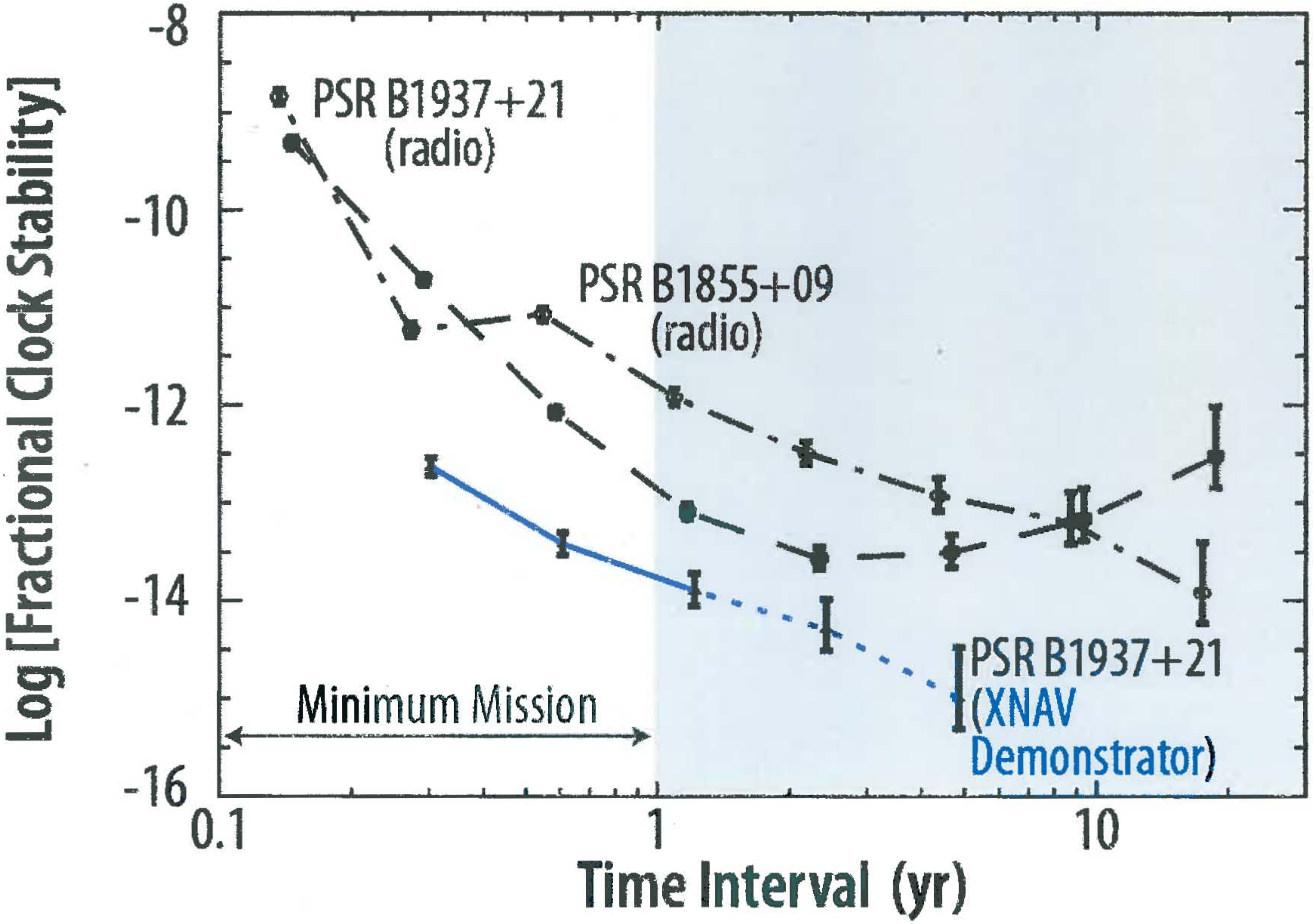


Clocks and Navigation

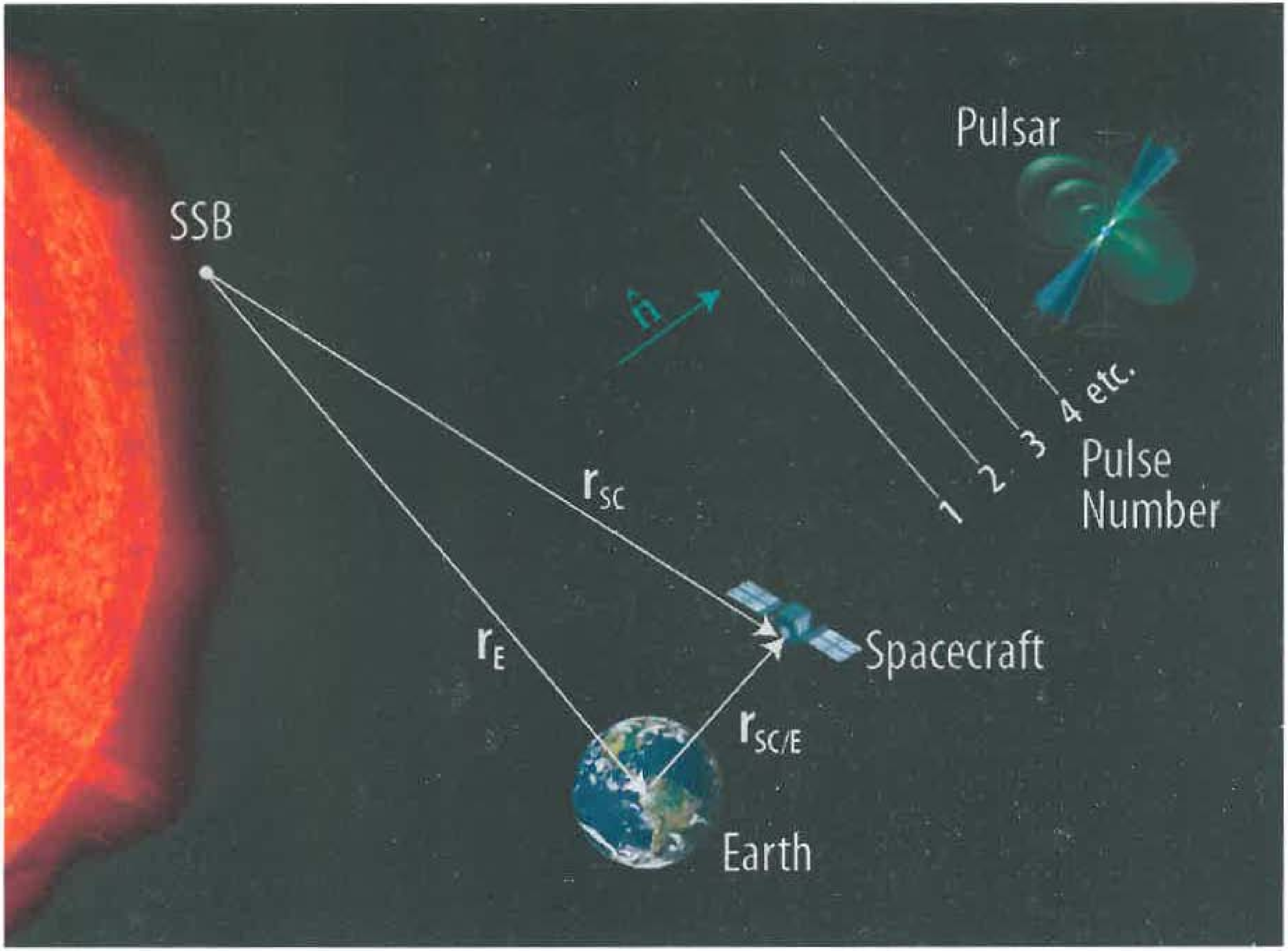
- You find atomic clocks on GPS satellites that provide the infrastructure for a navigation solution that works on the Earth and nearby…

- Pulsars are distributed on a Galactic scale providing a natural infrastructure for a GPS-like navigation solution that works throughout the Solar system and beyond.

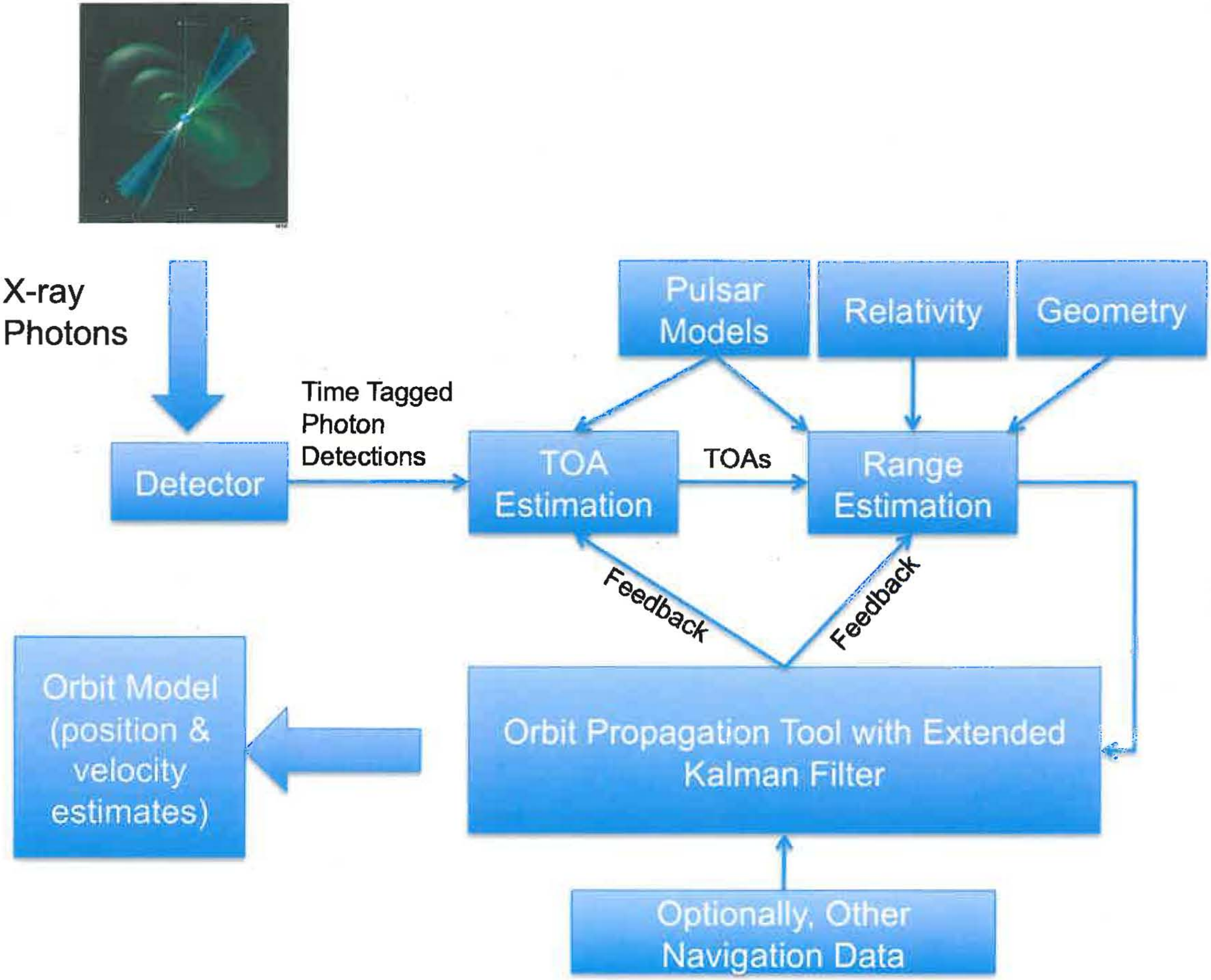
Pulsars are very stable clocks that are comparable or better than atomic clocks on long time scales



XN016



Pulsar
SSB
$\hat{n}$
4 etc.
3
2
1
Pulse Number
$\mathbf{r}_{SC}$
$\mathbf{r}_E$
Spacecraft
$\mathbf{r}_{SC/E}$
Earth



X-ray
Photons

Detector

Time Tagged
Photon
Detections

TOA
Estimation

TOAs

Pulsar
Models

Relativity

Geometry

Range
Estimation

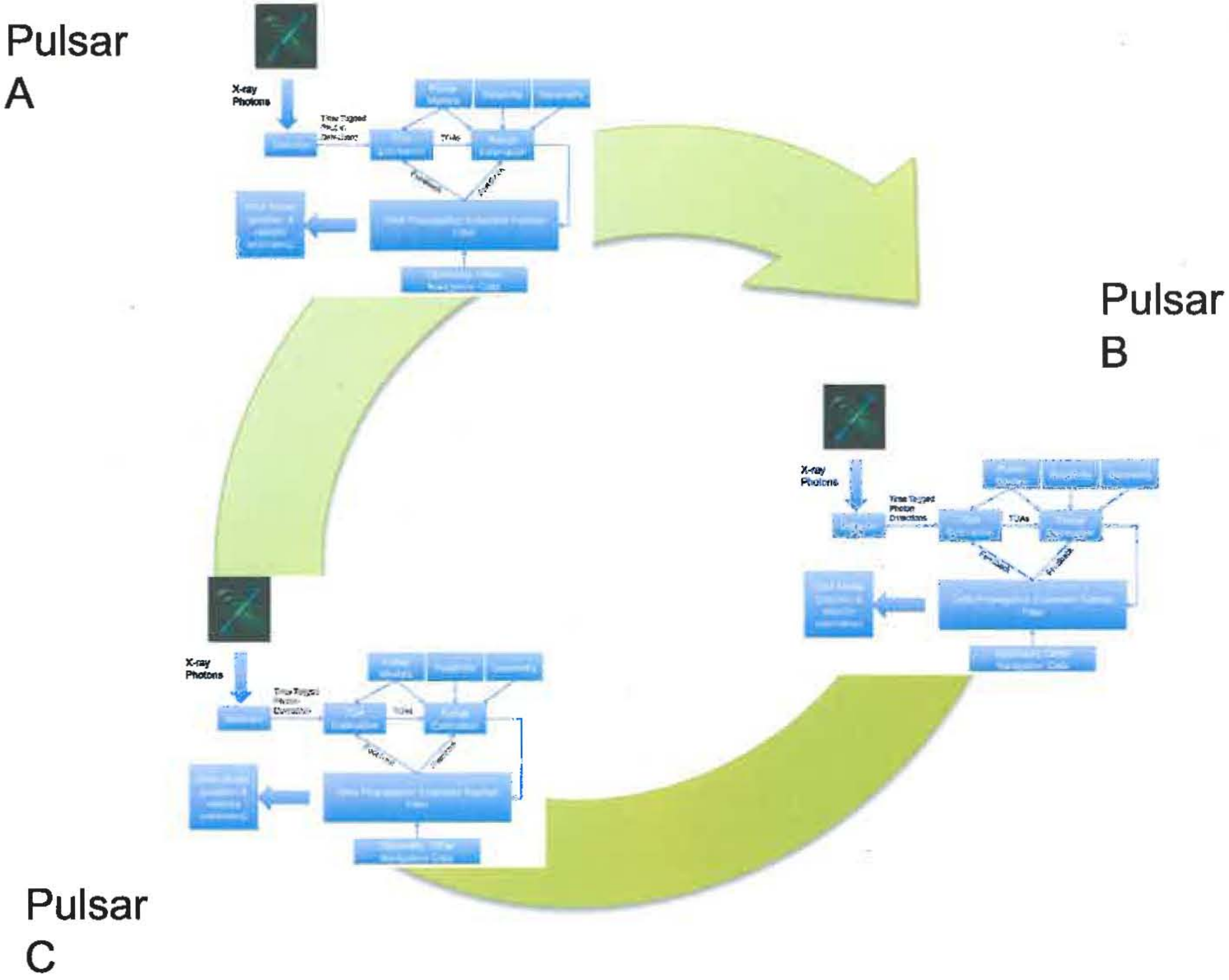
Feedback

Feedback

Orbit Propagation Tool with Extended
Kalman Filter

Optionally, Other
Navigation Data

Orbit Model
(position &
velocity
estimates)



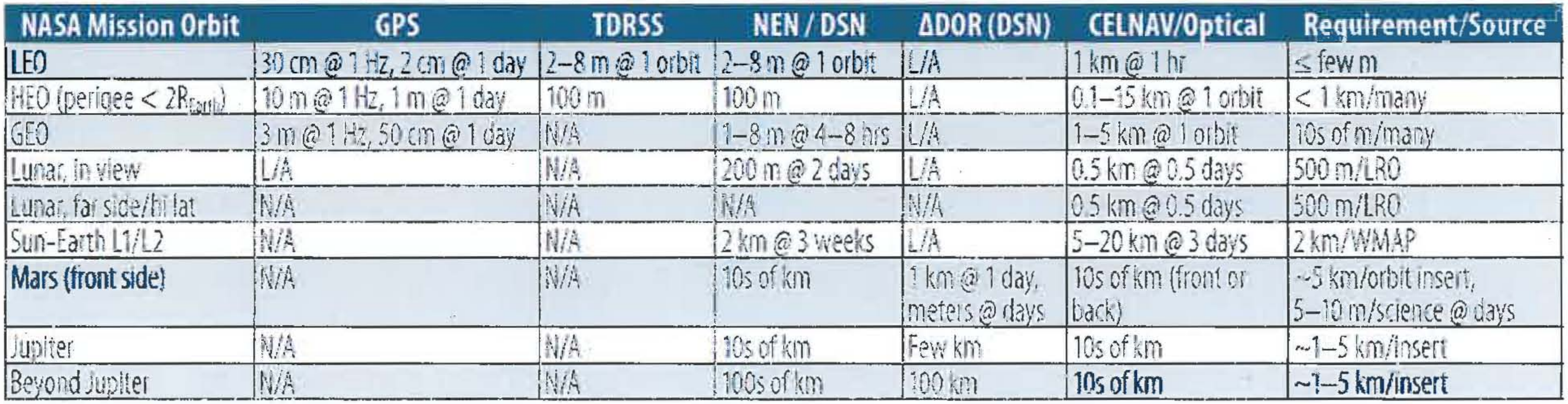
3D Solutions by stitching together observations of multiple pulsars

Expected Accuracy

- Dependent on orbit
  - How fast things change
  - Integration time on pulsars
- < 500 m for LEO orbit in a day
  - Timescale for updates 1000s of seconds
- < 100m for interplanetary in a few days

XNAV compared to other deep space navigation tools

Table 1: With typical position determinations to 500 m in one day or less virtually anywhere in the Solar System, XNAV provides unprecedented, mission-enabling navigation solutions across a wide range of space applications. (L/A: Limited Applicability, N/A: Not Applicable)



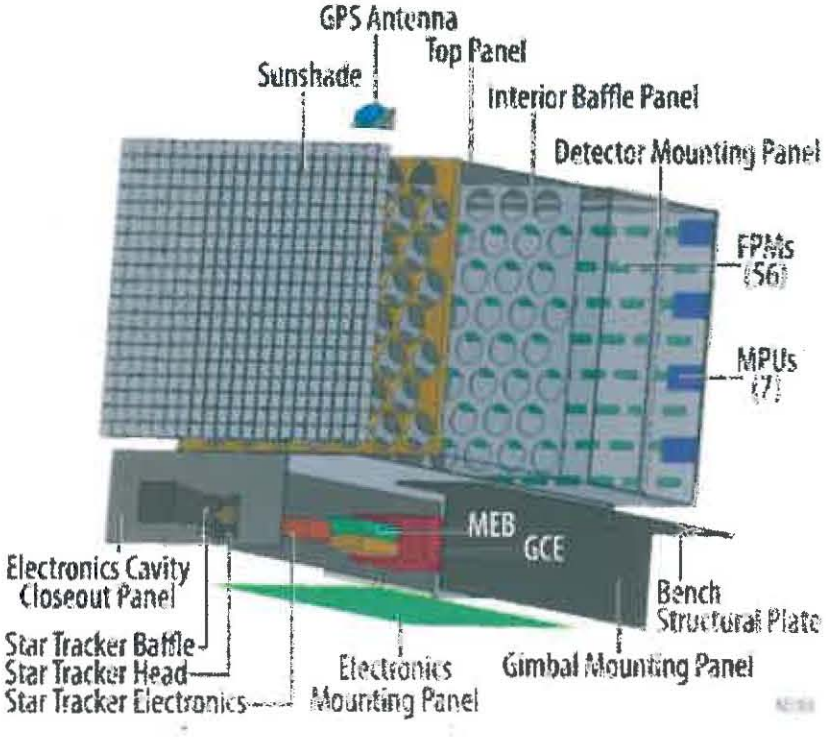
NASA Mission Orbit	GPS	TDRSS	NEN / DSN	ΔDOR (DSN)	CELNAV/Optical	Requirement/Source
LEO	30 cm @ 1 Hz, 2 cm @ 1 day	2–8 m @ 1 orbit	2–8 m @ 1 orbit	L/A	1 km @ 1 hr	≤ few m
HEO (perigee < $2R_{Earth}$)	10 m @ 1 Hz, 1 m @ 1 day	100 m	100 m	L/A	0.1–15 km @ 1 orbit	< 1 km/many
GEO	3 m @ 1 Hz, 50 cm @ 1 day	N/A	1–8 m @ 4–8 hrs	L/A	1–5 km @ 1 orbit	10s of m/many
Lunar, in view	L/A	N/A	200 m @ 2 days	L/A	0.5 km @ 0.5 days	500 m/LRO
Lunar, far side/hi lat	N/A	N/A	N/A	N/A	0.5 km @ 0.5 days	500 m/LRO
Sun-Earth L1/L2	N/A	N/A	2 km @ 3 weeks	L/A	5–20 km @ 3 days	2 km/WMAP
Mars (front side)	N/A	N/A	10s of km	1 km @ 1 day, meters @ days	10s of km (front or back)	~5 km/orbit insert, 5–10 m/science @ days
Jupiter	N/A	N/A	10s of km	Few km	10s of km	~1–5 km/insert
Beyond Jupiter	N/A	N/A	100s of km	100 km	**10s of km**	**~1–5 km/insert**

XNAV provides more utility compared to existing navigation methods as we venture further away from Earth.

At the greatest distances, the "Deep Space Network" (DSN) provide excellent distance information from the earth, but MUCH less information in the cross-direction.

The Instrument

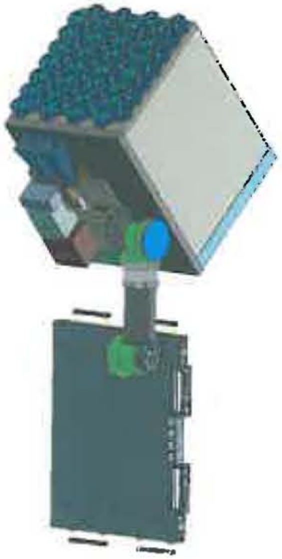
SEXTANT Payload



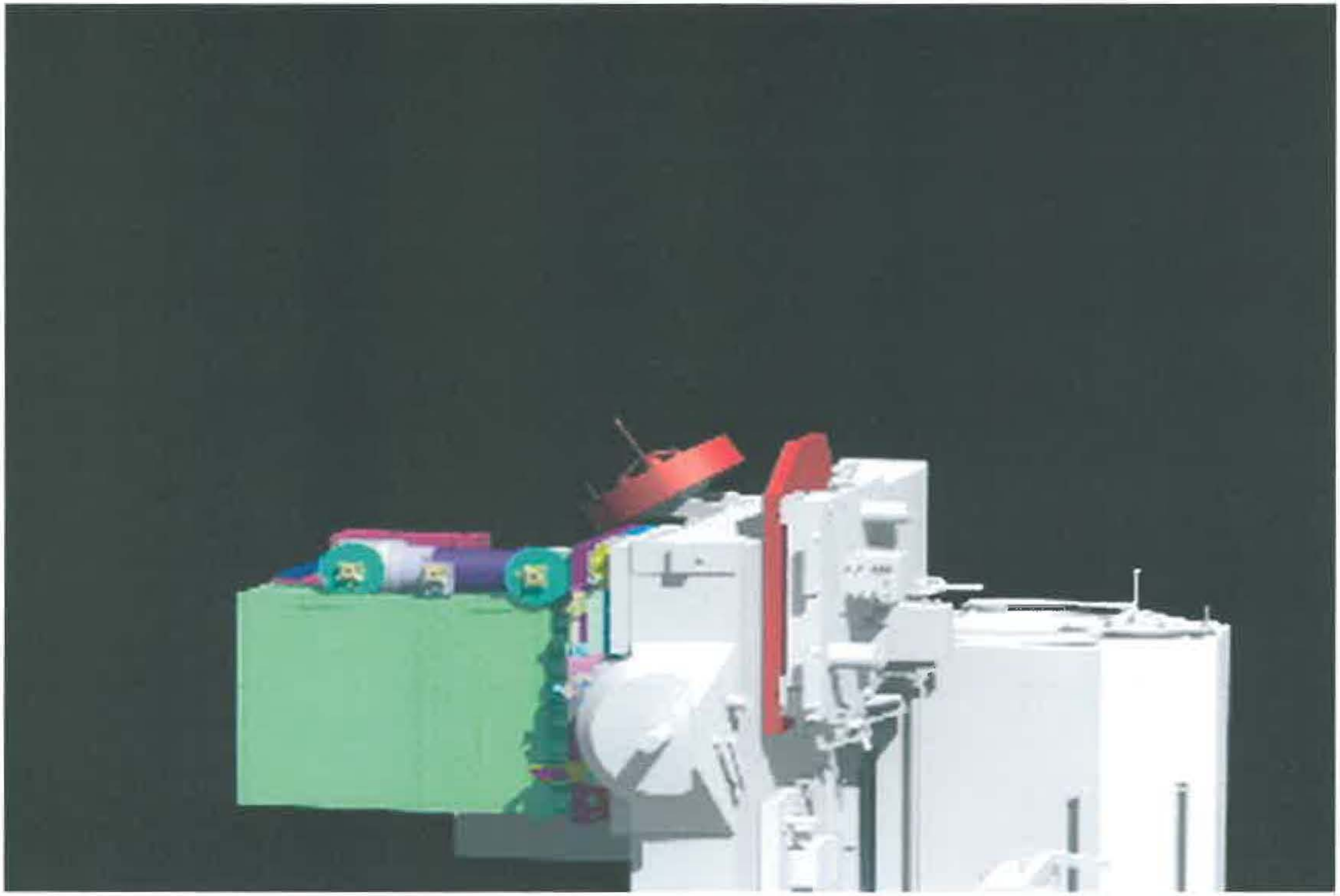

Stowed


Deploying

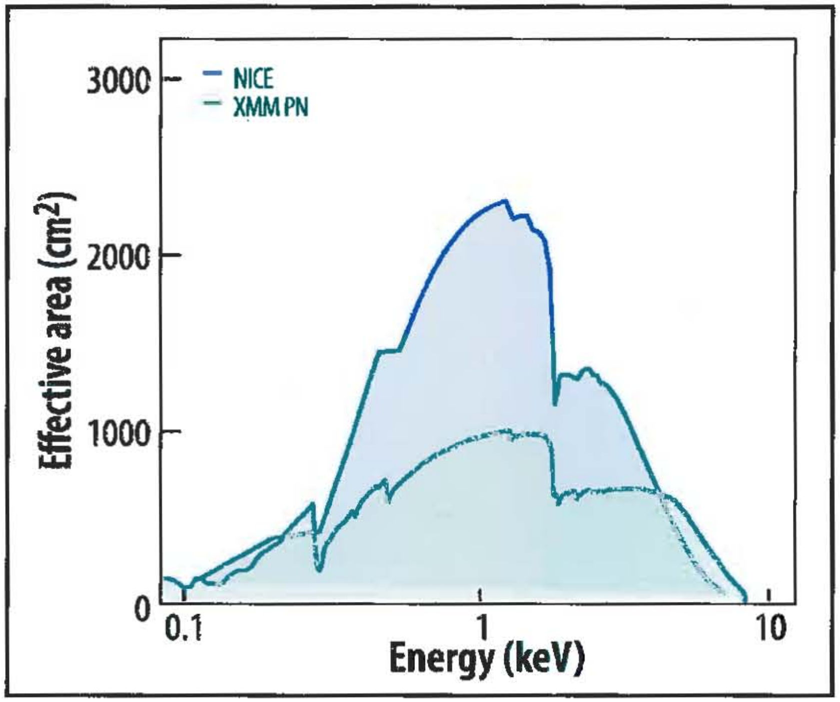
- 56 co-aligned X-ray concentrators with matching Silicon Detectors
- < 200 nsec absolute time resolution
- > 2000 cm^2 Effective Area
- Moderate (CCD-like) energy resolution


Pointing

Deployment and pointing scheme



SEXTANT OPTICS



1st partial assembly of XACT optics

1st optical image from XACT optics FWHM ~< 1 arcmin

- Derivatives of GSFC foil optics- continued legacy of Peter Serlemitsos
- Single bounce concentrators
- Full shells with deviation from cone
- Order of magnitude improvement on area/ mass ratio
- XACT sounding rocket will use similar optics

The X-ray Detectors

- Silicon Drift Detectors
- Commercial with Custom Designed Electronics
- Excellent Timing capability and Energy Resolution
  - But there is still a timing jitter term
- Summer 2010 USNA Midshipman Spencer Ewing Project

Background

- Incident X-rays enter silicon; energy frees electron from silicon atoms.

- Concentric drift rings are charged at increasingly negative voltages outside of the center signal anode.

- Drift rings guide freed electrons to move toward central sensing signal anode.

- Signal anode is read out by a preamplifier that converts the charge signal to a voltage signal.

- The further the initial X-ray interaction is from the sensing anode, the longer the drift time.

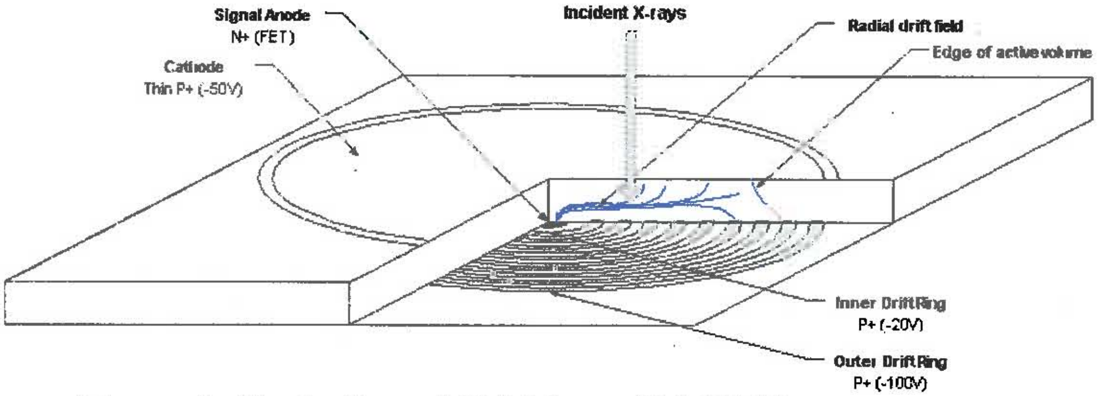


Figure 1: Illustration of SDD from AMPTEK

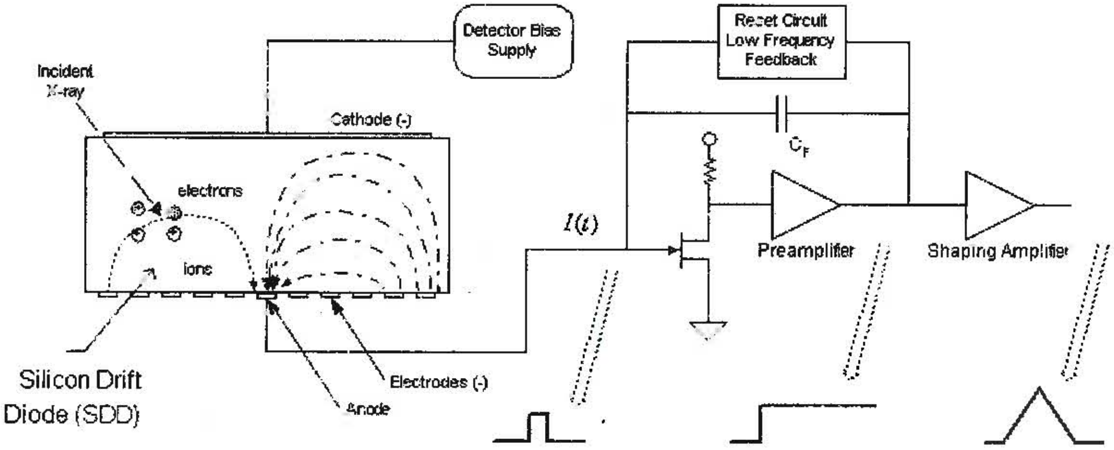
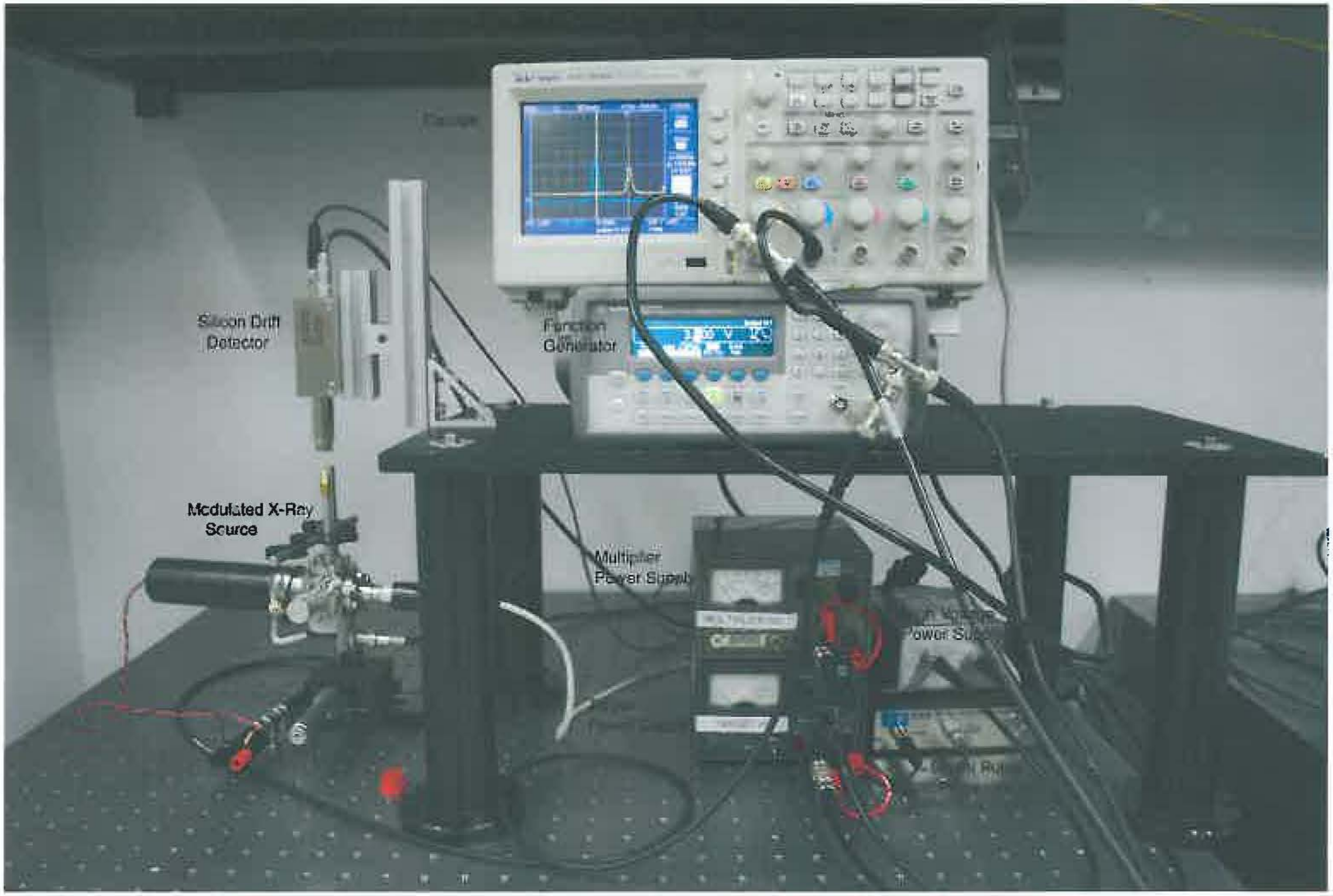


Figure 2: Diagram of how the SDD works from AMPTEK

Experiment Setup

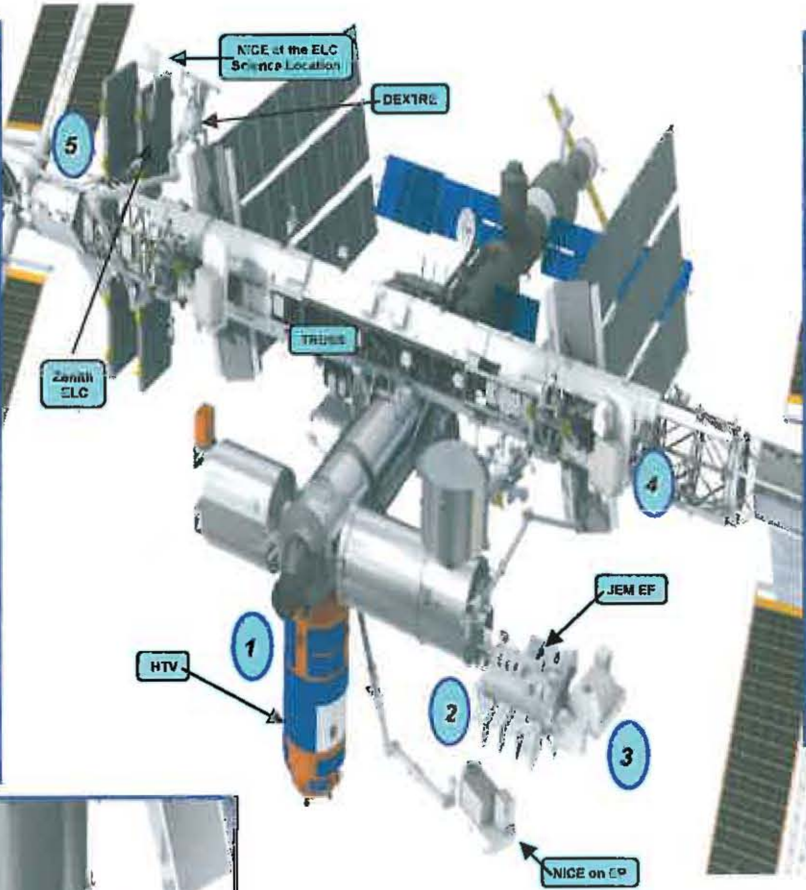


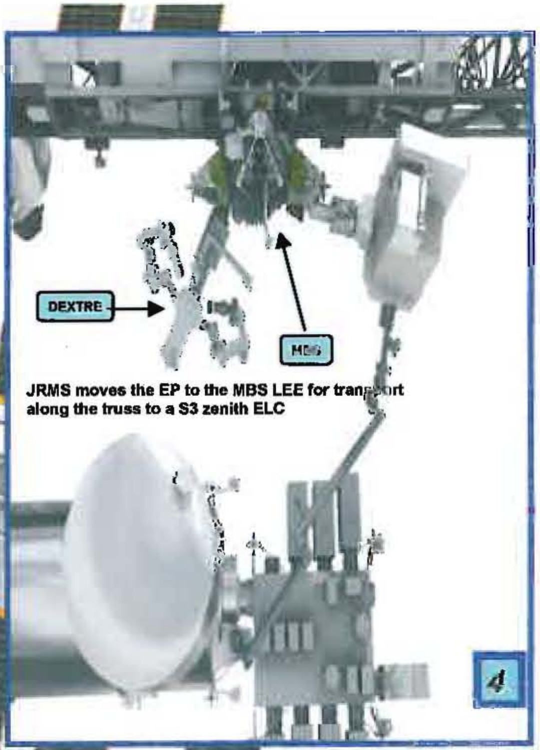
Function Generator (FG) the modulated X-ray source, producing a 60nsec wide pulse done at a 500 kHz rate.
Additional power supplies needed to power the MXS.
Data Acquisition compiled by Digital Pulse Processor, relayed to Oscope.
Scope averaged 100 triggers of data to reduce errors.

Operations Concept

- Getting from the Earth to ISS
- Robotic Installation
- Getting the science done, once we are there
  - USNA Midshipman Putbrese is working with Prof Tae Lim and GSFC engineers on a planning tool.

DEXTRE removes NICE from the EP and installs onto ELC





JRMS moves the EP to the MBS LEE for transport along the truss to a S3 zenith ELC

HTV berthed to ISS At NODE2. SSRMS Removes the EP from HTV

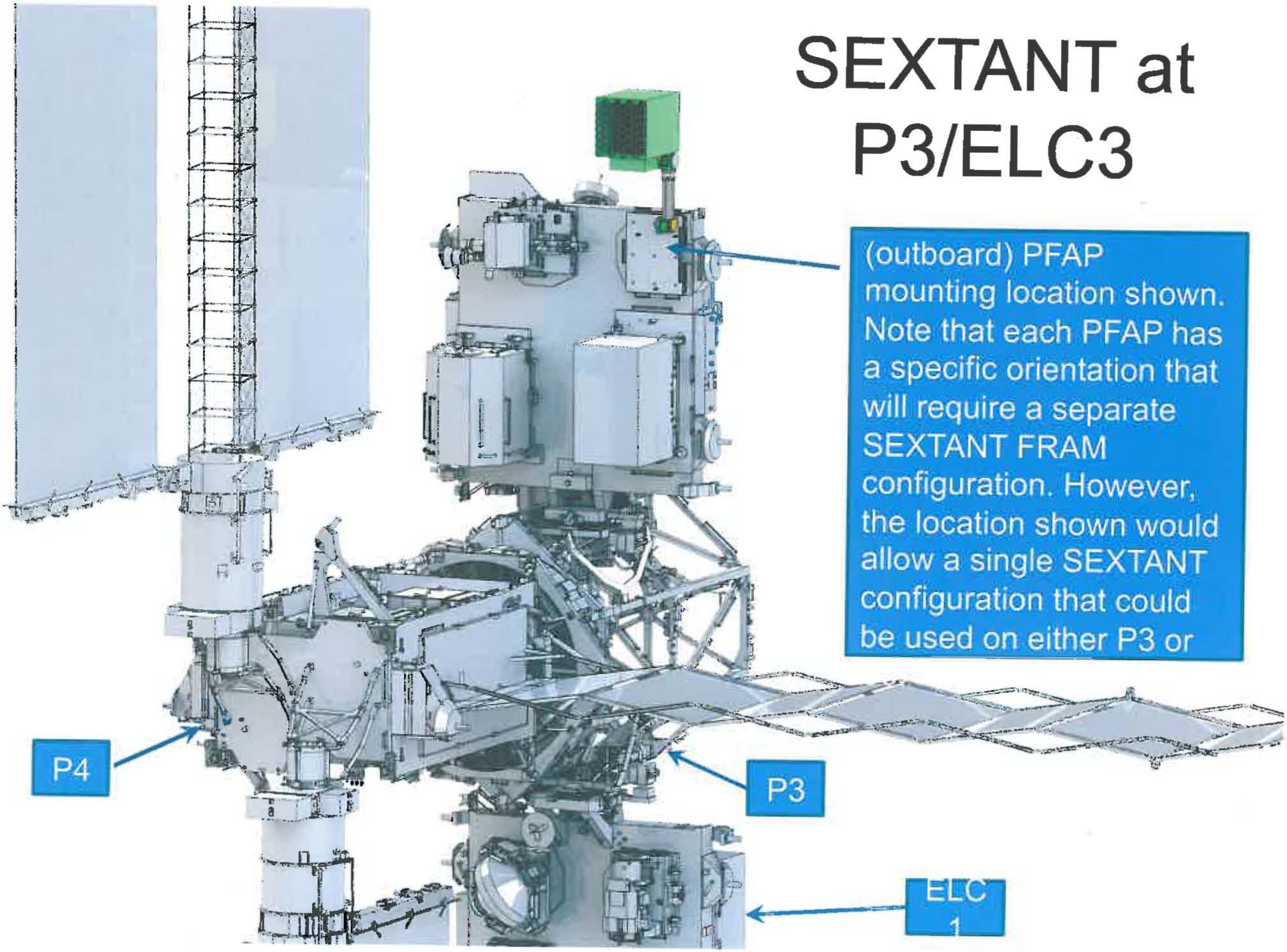
SSRMS handoff EP to JRMS

The NICE payload arrives at ISS on the External Pallet within the exposed logistics module of the HTV. After the HTV is berthed to Node 2, the SSRMS removes the External pallet (EP) from the HTV (1). Once clear of the HTV, the SSRMS positions the EP so it can hand it off to the JRMS (2). Once the JRMS grapples the EP, it moves the EP to a temporary storage attach point (3) on the JEM Exposed Facility (JEM-EF) where is remains until ready for installation on the zenith S3 Express Logistics Carrier (ELC).

The JRMS removes the EP from the temporary attach point and moves it to the Latching End Effector (LEE) on the Mobile Base System (MBS) (4). Once attached, the MBS translates the EP, as well as the SSRMS and DEXTRE starboard from the P1/P3 Truss to the S3 Truss. The DEXTRE robot is installed onto the end of the SSRMS, DEXTRE removes NICE from the EP and installs it onto the zenith ELC (5).

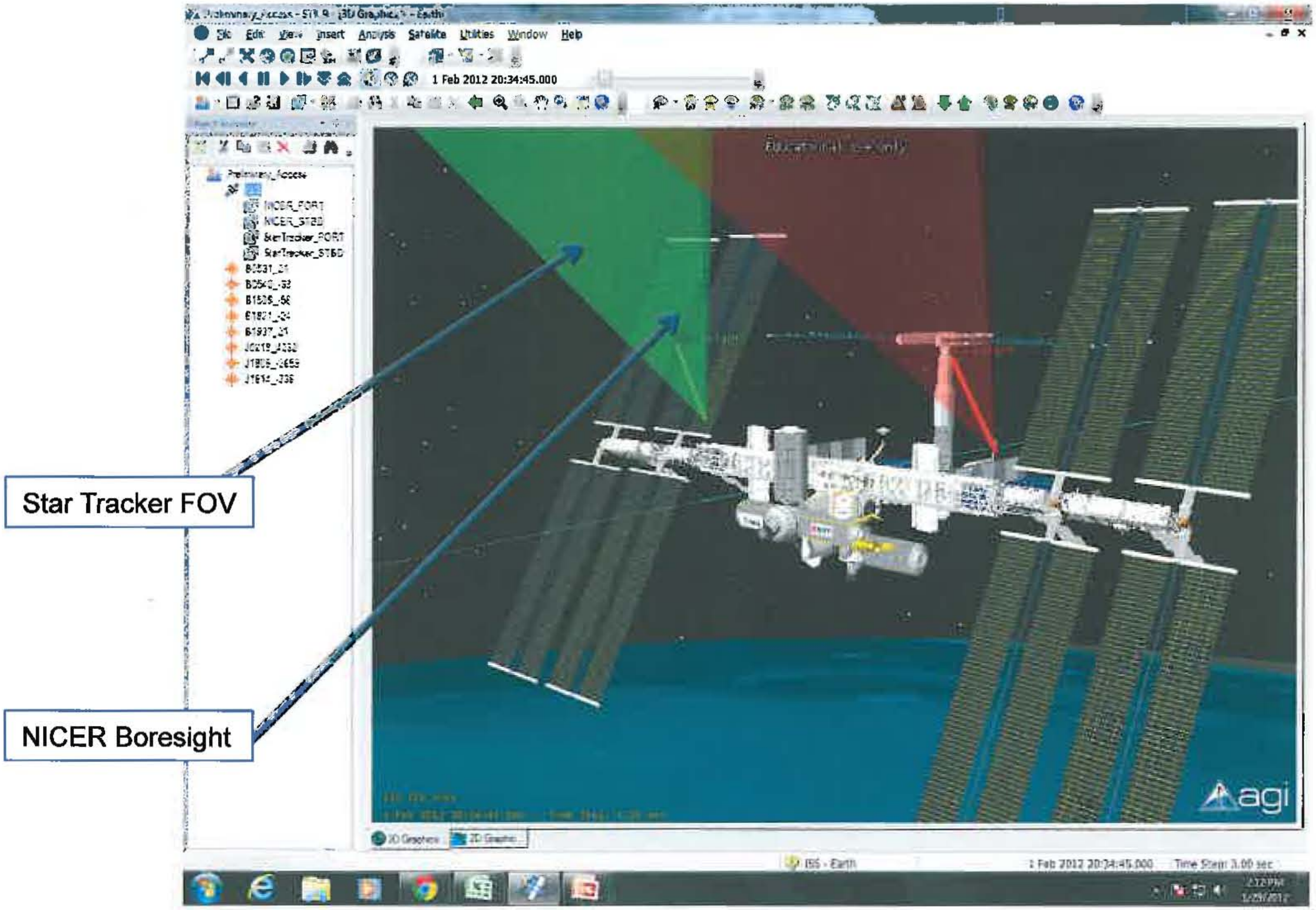
JRMS berths EP at a temporary storage point on the JEM EF

SEXTANT at P3/ELC3



(outboard) PFAP mounting location shown. Note that each PFAP has a specific orientation that will require a separate SEXTANT FRAM configuration. However, the location shown would allow a single SEXTANT configuration that could be used on either P3 or

3-D Model – ISS


File
Edit
View
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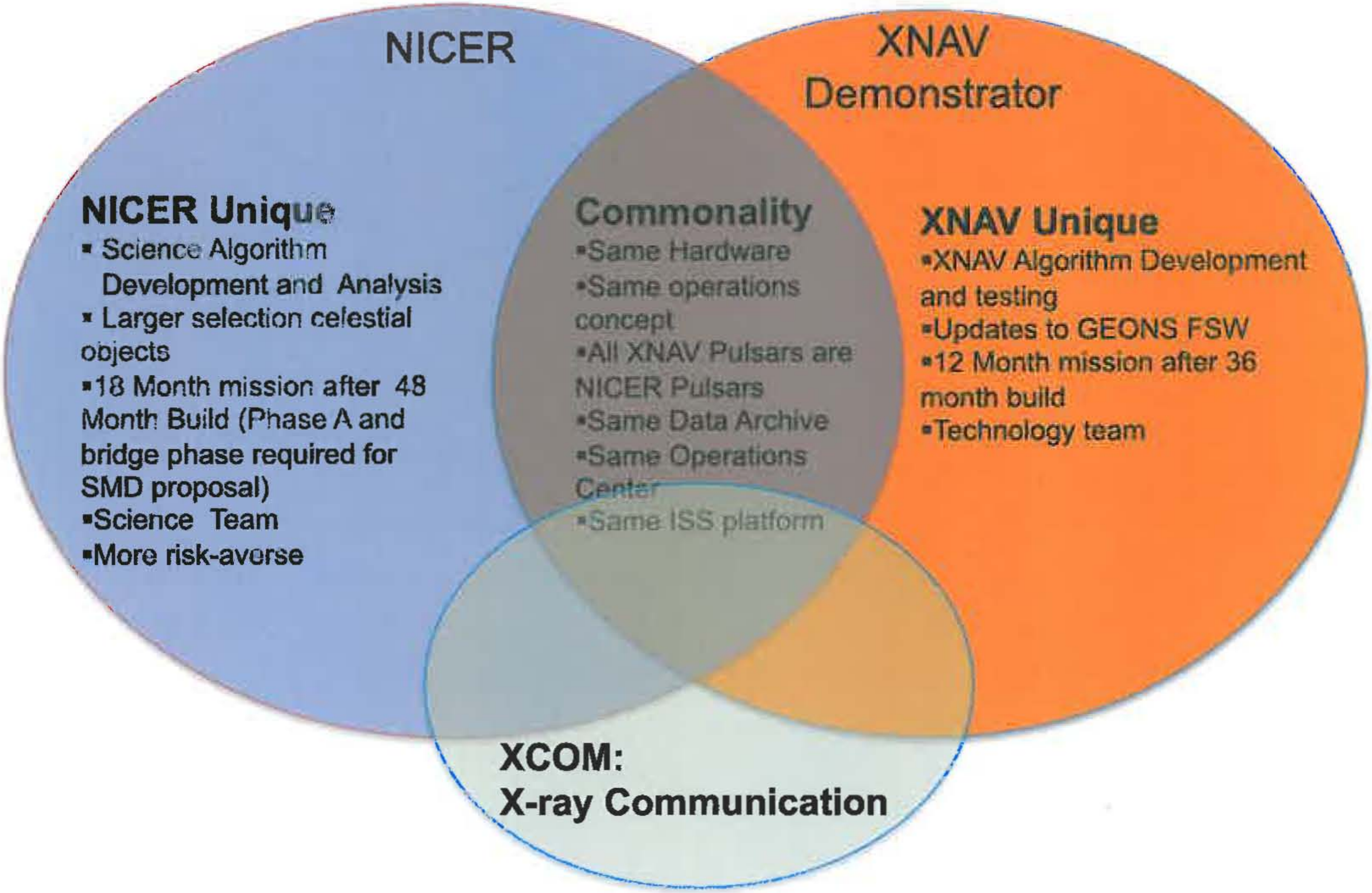
Satellite
Utilities
Window
Help
1 Feb 2012 20:34:45.000
Preliminary_Access
NICER_PORT
NICER_STBD
StarTracker_PORT
StarTracker_STBD
Educational Use Only
agi
3D Graphics
2D Graphics
ISS - Earth
1 Feb 2012 20:34:45.000
Time Step: 3.00 sec
Star Tracker FOV
NICER Boresight

Science and backup

SEXTANT: Station Explorer for X-ray Timing and Navigation Technology



NICER

XNAV
Demonstrator

NICER Unique

- Science Algorithm Development and Analysis
- Larger selection celestial objects
- 18 Month mission after 48 Month Build (Phase A and bridge phase required for SMD proposal)
- Science Team
- More risk-averse

Commonality

- Same Hardware
- Same operations concept
- All XNAV Pulsars are NICER Pulsars
- Same Data Archive
- Same Operations Center
- Same ISS platform

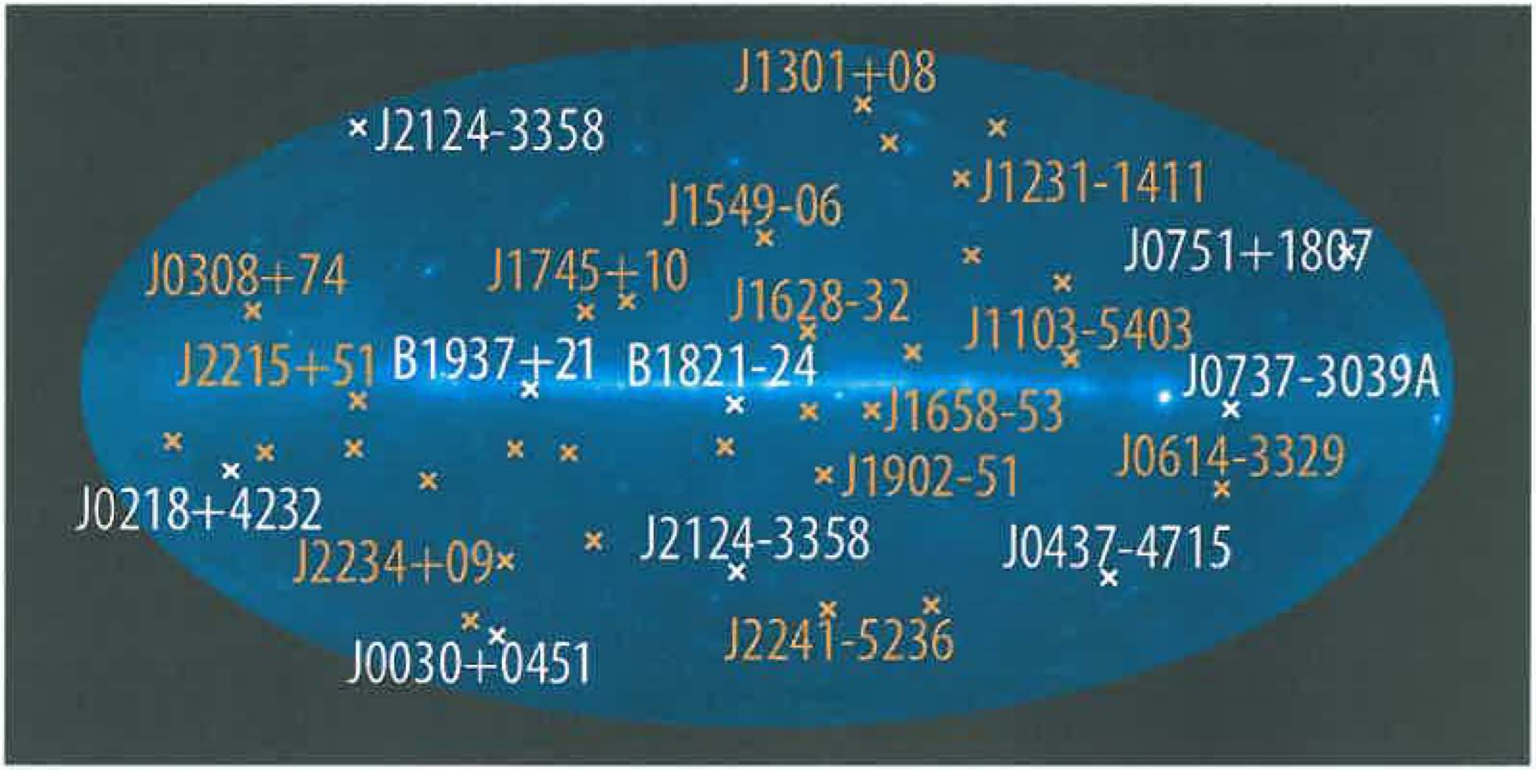
XNAV Unique

- XNAV Algorithm Development and testing
- Updates to GEONS FSW
- 12 Month mission after 36 month build
- Technology team

XCOM:
X-ray Communication

SEXTANT = NICER + XNAV +XCOM

Ongoing Millisecond Pulsar Discoveries Promise Many New NICER Targets!



What is the best way to detect the pulses of a Pulsar?

- Radio
  - 10m diameter dishes or greater
  - RF propagation terms
- Optical
  - Very Faint-> requires large telescope
- X-ray
  - ~ few hundred square cm of area good enough
- Gamma Ray
  - massive detectors required

X-ray Navigation (XNAV)

EXTANT Dragon Deployment

Preliminary!!

1. Dragon berthed at Node 2 Nadir. SSRMS/SPDM removal from trunk. SPDM stows SEXTANT on EOTP

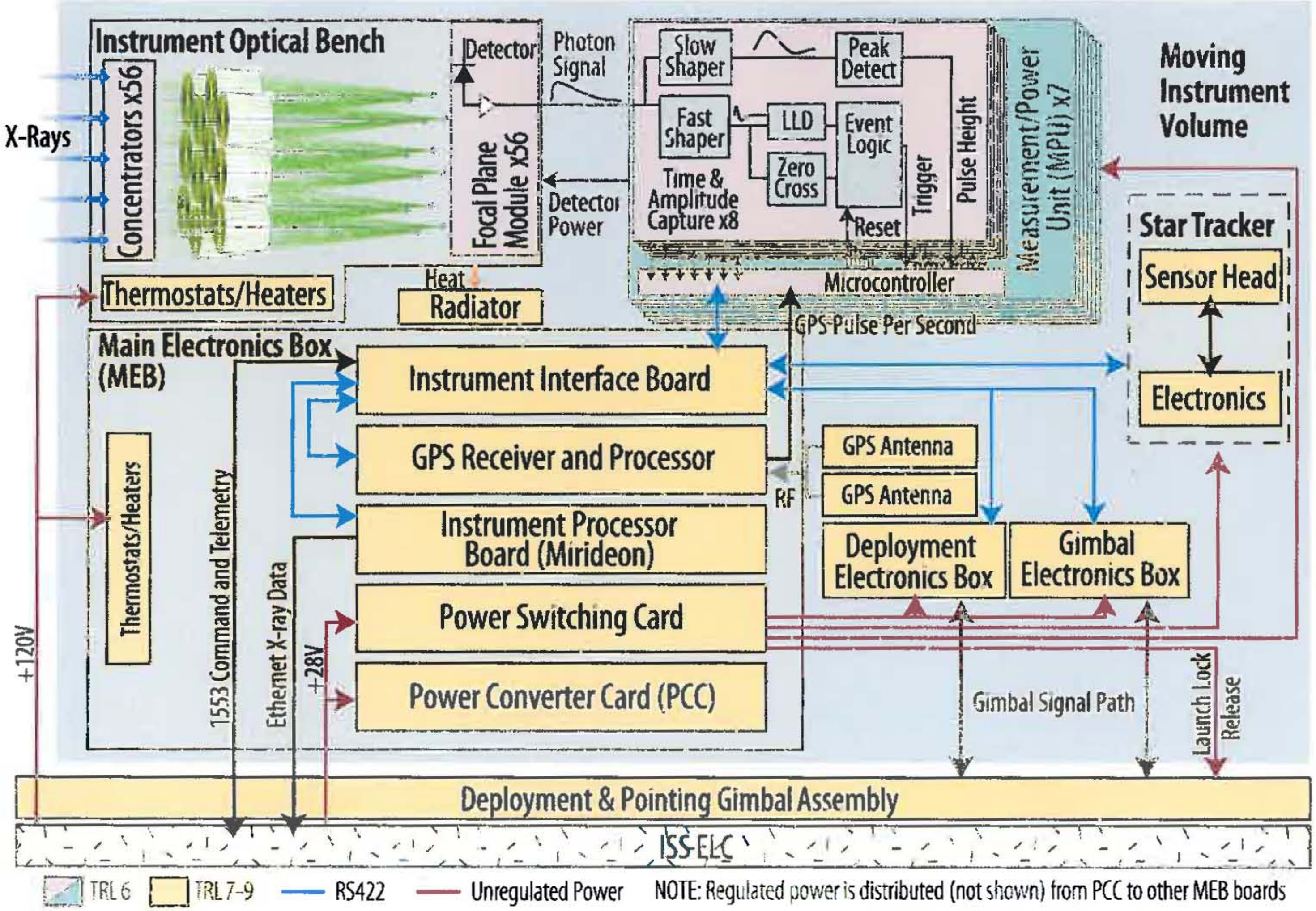
2. SSRMS berths SPDM (with SEXTANT on EOTP) on US Lab PDGF. SSRMS reconfigures onto MBS PDGF.

3. SSRMS grapples SPDM (with SEXTANT on EOTP)

4a. MBS (with SSRMS and SPDM) translates to S3 worksite. SPDM removes SEXTANT from EOTP and installs onto ELC2

4b. MBS (with SSRMS and SPDM) translates to P3 worksite. SPDM removes SEXTANT from EOTP and installs onto ELC3

Instrument Block Diagram



NOTE: Regulated power is distributed (not shown) from PCC to other MEB boards

Instrument Performance		
Bandpass & Effective Area	0.2-12 keV 2300 cm^2 @ 1.5 keV, 600 cm^2 @ 6 keV	
Energy Resolution	3% @ 6 keV, 10% @ 1 keV	
Timing Resolution	Detector	150 ns
	GPS to UTC	50 ns
	GPS pos'n	30 ns
	Total RSS	**161 ns**
Spatial Resolution	3 arcmin	
Pointing Control Budget (arcsec)	Control	50
	Boresight	15
	ISS Jitter	11
	Thermal	11
	Tracker	2
	Total RSS	**76**
Sensitivity (unpulsed), 0.4-10 keV	2.2×10^{-14} ergs/s/cm^2, 5σ in 10 ksec	