IXPE
Imaging
X-Ray
Polarimetry
Explorer

IXPE Science Operations
NICER/IXPE Workshop

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Allyn Tennant

Preliminaries

- **IXPE was never intended to be fast response spacecraft**
  - Typical observations take about week, hence waiting a few days should make no difference
- **Neither SOC nor the MOC are 24/7 operations**
  - It is a low-cost mission with minimal direct interaction with the spacecraft
  - Budgets are being squeezed
- **Forget what you know about Swift and NICER response times**
  - Our drivers are totally different

Objectives

- **This is a look "behind the curtain" of IXPE operations**
  - Make some of operations less mysterious
  - Only indirectly will help you write better proposals
  - Will not focus on issues of software or data analysis

- **We are spatially separated**
  - The Science Operations Center (SOC) is at Marshall Space Flight Center in the Central (US) time zone
  - The SOC lead (me) remote works in the Eastern time zone
  - The Mission Operations Center (MOC) is at Laboratory for Atmospheric and Space Physics (LASP) in the Mountain time zone
  - The prime spacecraft contractor is at BAE (formally Ball) also in Mountain time zone
  - The instrument team is in Italy
  - HEASARC is at Goddard Space Flight Center

Data Volume

- **IXPE generates more data per event than any previous X-ray mission**
  - Takes a picture of every electron track
  - Limited on-board storage
    - 4 GB for event data
  - Limited number of ground stations
    - Inclination is effectively zero degrees
    - Malindi is prime
      - Average use is every other pass (7.5 passes per day)
    - Singapore is backup
      - Can be used a few times per week
      - (can not be used at certain times of the day)
    - Planning must allow for missed contacts
  - Telemetry load is very important
    - Totally drives planning for bright sources

Ground Operations

- **IXPE operates with minimal ground interaction**
  - The spacecraft holds the observing plan for an entire week
  - The plan includes all contact times
    - When spacecraft flies over a ground station at a scheduled contact time it
      - Turns on transmitter
      - Transmits a block of data
      - Resets the pointers
    - Note, the spacecraft does this whether or not there is full two-way communications
      - If ground station is not ready, then there will be a large gap in the data
      - Since the spacecraft has reset pointers, it will not fill in gap, but continue on
      - The MOC needs to find this gap and manually request a re-transmission before the data are overwritten

Operations

- **There are often short gaps in the data**
  - Can be radio interference (lightning)
  - Often due to the spacecraft transmitting on two antennae
    - Can result in classic interference pattern in the signal strength
      - Not a hard cutoff, but gradual degradation of the signal
    - Resulted in an unexpected number of small files (100-1000s) early in the mission
      - Greatly slowed SOC processing
  - The MOC now predicts the times of destructive interference
    - Weekly load will pause transmission of data during the worst intervals
  - Can still get short gaps
    - Since the predictions are a week in advance predictions can be slightly in error
    - Trade off between getting as much data as possible when you can

Re-transmissions

- **The MOC needs to identify all gaps in the data and request re-transmission of the missing data.**
  - Gap checker is now automated
  - Re-transmission requires more interaction with the spacecraft
    - Verify two-way communication
    - Need to pause the current download
    - Transmit commands to dump blocks of missing data
    - Resume normal download
- **Even when the MOC has all the data, the SOC still sees gaps**
  - We then request that the MOC re-send the data
  - This adds another couple of days to the collecting all the data

Data Download Timeline

- **Worse case is it can take a week to get data from a bright source off the spacecraft**
  - Often takes less, but cannot assume that when planning
- **Allow another couple of days for MOC to find and fill gaps**
- **Allow another couple of days for the SOC to request resend of any missing data**
- **For long observations SOC processing can take several days**
- **Can take up to two weeks to process data**
  - Often done in less time

Segmenting and Exclusive Use

- **IXPE data by NASA HQ rules have no exclusive use period**
  - An exception can be requested in your proposal and can be granted (decided by NASA HQ)
- **To discourage people publishing results based on incomplete observations, we only distribute data for completed observations**
  - Completion includes all data from one observation that can be obtained in one 6-month season
  - The clock starts when we distribute data to the HEASARC
  - The PI is not given a “head start”
- **If this is fine, ask for one observation**
  - We will segment as needed
- **If you want the data quickly ask for multiple observations**
  - Each dataset will be distributed when completed
  - Put a note in RPS saying the observations do not need to be spaced out

SOC Planning

- **The Long-Term Planning begins when SOC gets the target list**
  - Includes observing constraints
    - Normal phase constraints such as
      - Avoid X-ray eclipses
      - Observe at peak of super orbital period
    - Want to space out observations in time but not by too much
    - Avoid times around full Moon
  - Some checking of targets is performed
    - Up to observer to get the numbers right
  - Bright sources need to be broken up into “4 GB chunks”
    - Need to observe a faint source while on-board storage is read down
    - Want to get back to bright source quickly
      - Results in the faint target also being segmented
    - Want all segments to occur in the same 6-month season
  - Planning is a “packing problem”
    - Need to lay out the full year to make sure last targets are visible at the end of the year
      - Since ToO’s can change the plan, only 6 months are published

Normal Planning Cycle

- **From the LTP, the SOC prepares a 3 week list of targets one week in advance**
  - This list is called an Instrument Activity Plan (IAP)
  - IAP includes name, position, data rate and exposure time
    - Does not contain observation start/stop times
  - The MOC prepares a “slew report” for all 3 weeks
    - The MOC plans slews to occur during Earth occultation of the target
    - Provides feedback to SOC when observations begin and end
    - For time critical observations we will adjust the exposure times to be consistent with LTP
    - We only control to 6 hours
  - The MOC also looks at how bright the upcoming targets are
    - If a bright target is coming up, the MOC will request additional contacts for that week
    - Ground station requests go in 3 weeks in advance
  - The MOC plans the upcoming week
    - Includes all spacecraft activities (contacts/slews/etc.)
    - Plan is checked and approved by MOC, SOC and BAE

The Planning Timeline

- **The SOC produces an IAP on Wed afternoon and submit to MOC on Thurs morning**
- **The MOC produces the slew report by Friday**
- **The MOC plans the upcoming week (12 UT on Thurs to 12 UT following Thurs)**
- **The draft command load appears on Tues**
  - The command load is abstracted and posted at
    - https://ixpe.msfc.nasa.gov/for_scientists/weekly.html
- **On Wed the commands for the entire week are loaded to spacecraft**
  - Goal is to have two chances to upload during working hours at MOC
- **At 12 UT on Thurs the new command load takes over control**

SOC stuff

- **After each contact, the MOC collects data from the ground station**
  - Then forwards all data to the SOC
    - “Science” and Spacecraft data come in separate data streams
      - Raw instrument will contain separate gaps
      - Will need both to process data
  - Instrument data are sent to the Italian Team for health and safety monitoring
- **When data set is as complete, processing begins**
  - Apply detector corrections as provided by the instrument team
    - Charging impacts the detector gain and depends on how bright the target is
      - Need to integrate the charge history to get current charge state (hence the gain)
      - Requires a complete set of data
      - Charging model is still not totally correct
  - Actual boom motion was much larger than predicted pre-launch
    - We created a model for the boom motion which is applied
    - For bright sources, we apply an X-ray aspect solution
  - Final level 1 and 2 products are produced
    - SOC lead does a quick inspection of data before it is released

ToO Considerations

- **ToO's can impact the normal planning in 1 of 3 ways**
  - If the ToO is 3-4 weeks out, we just change the LTP
  - If the ToO can start after 12 UT a week from upcoming Thurs we can tweak the IAP
  - If the ToO impacts the planned or what's on the spacecraft, then the MOC must replan the load
- **A pre-approved ToO is considered must do**
- **All other ToOs are considered to be Director's Discretionary Time**
- **All ToO's are subject to a review process that includes external scientists**
  - Review takes place in parallel with the planning
- **Friday afternoon is the worse time to submit a ToO**
  - Already planning the following week
- **Monday/Tuesday is better**
  - Very helpful if target can be observed a week from the upcoming Thurs
- **Depends on what is currently on the spacecraft**
  - If the ToO is bright and we just observed a bright target, may need to wait

ToO Planning

- **In all cases the following key steps are needed**
  - The MOC is alerted that a ToO is being considered
  - The coordinates and estimated count rates are checked
  - We update our data base
  - Figure out when the commands can be uploaded to the spacecraft
    - Depends on contacts, for faint sources may not have a lot of choices
      - May require a request for an additional contact
  - The LTP is reworked in two phases
    - First (before the IAP is submitted)
      - Minimize disruption to overall plan
      - Takes into account the amount of storage currently in use
      - Add new target so that it does not violate the storage limits
    - Second (after IAP is submitted to MOC
      - Restore any cat A bumped targets
      - Try to complete any observation that had been started
  - IAP is created and provided to MOC

Spacecraft Issues

- **Star tracker**
  - We have one star tracker with 2 heads
  - Sometimes one head is searching for stars, the other head is restricted to 5 stars
  - Has no noticeable impact on science quality
- **GPS**
  - Use for both timing and position
    - Instrument has a very accurate oscillator
  - Occasionally drops out
    - Requires a GPS restart
    - Early in the mission, this was a manual process
      - Never occurred during a fast (<1 sec) pulsar
      - We fill in GPS data using Two Line Elements (and added a note in the README file)
    - The spacecraft now detects this condition and automatically restart the GPS
      - GPS dropouts are now about a minute
      - For these cases we do not back fill that data with TLE data
      - Bad GPS times are not included in the Good Time Intervals

Spacecraft issues

- **Battery issue**
  - Battery is used every orbit which results in battery wear
  - Have reduced the heater power usage, increasing the lifetime
  - The entire team continues to look at ways to reduce wear
  - (LASP operates a spacecraft with a totally dead battery)
- **Fill Frame**
  - So far has happened twice, the spacecraft starts transmitting “fill frames”
  - Telemetry contains no useful data, however
    - Spacecraft is still executing the command load
    - Spacecraft will accept ground commands
  - Effectively required a reboot of the spacecraft
    - Restoring spacecraft to normal operations requires almost a week
  - Root cause not understood but BAE can simulate on the ground
    - Has a potential “work around” to restore telemetry without the reboot
    - Will be tested at next occurrence
    - If successful, will automate recovery
  - If data was not overwritten, it can be recovered off the recorder

Early SAA entry

- **During geomagnetic storms**
  - A magnetic trough West of the the South Atlantic Anomaly (SAA) fills with particles
  - IXPE enters this trough about 10 minutes prior to main SAA
    - Totally different from the small rate increase seen just before SAA entry
  - The detector count rate can reach very high levels
    - To protect the detector the spacecraft detects this condition
    - Instrument is commanded into SAA mode at this time
    - Note, upon SAA exit the on-board load normally commands SAA mode off
  - Other than slightly shortening the observation, has no impact on science

Conclusions

- **IXPE operates with a very small team**
  - Nominal 40-hour work week
  - The team is very dedicated and typically can be reached
- **A maximum amount is done on the spacecraft**
  - Does reduce flexibility
- **We try to accommodate as many science related requests as possible**
  - As in for all missions there are many trade offs that need to be considered

- **The primary task of the SOC is to help you get good science**