



# The Contingency of Success: Deep Impact's Planet Hunt

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This document has been reviewed for export control and it does NOT contain controlled technical data.

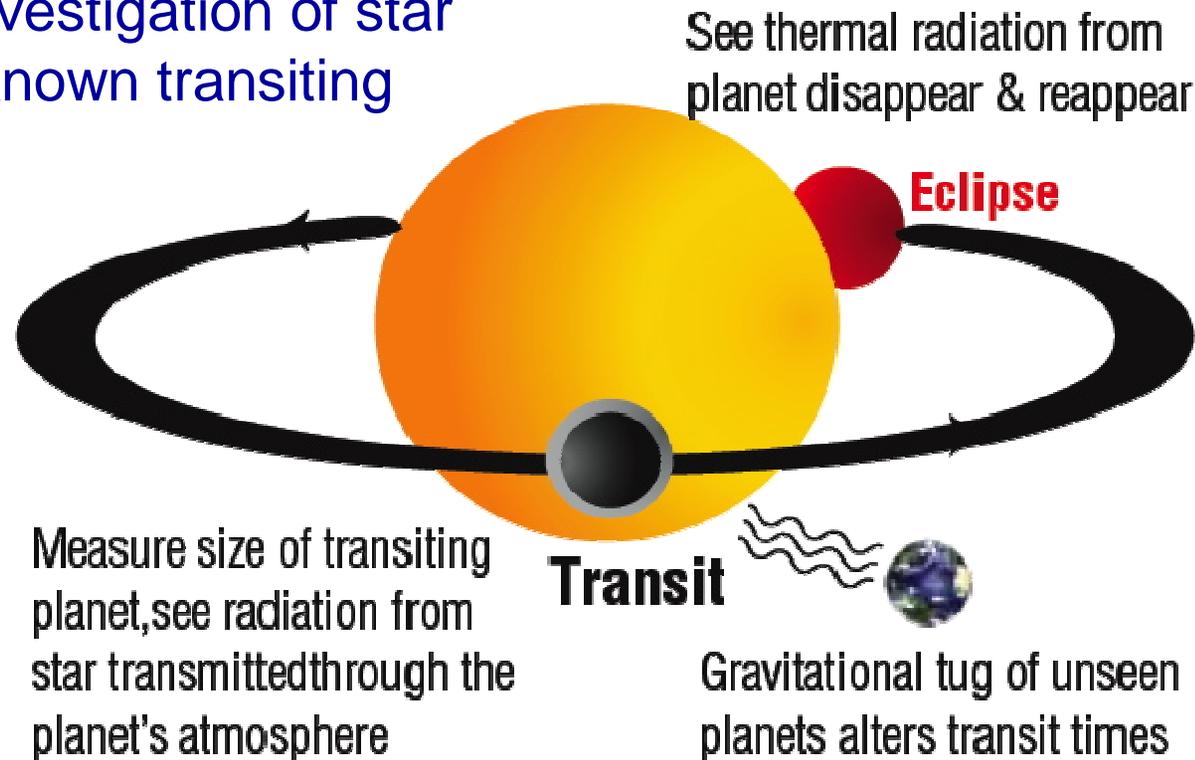
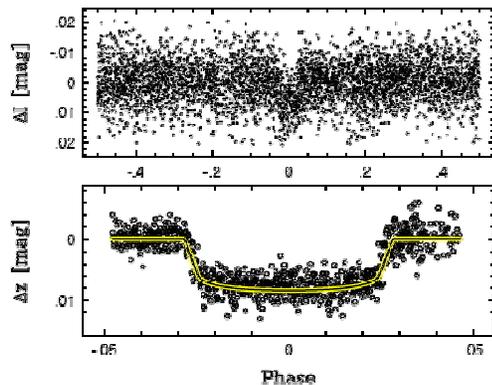
## What is EPOXI?

- ❑ EPOCH = **E**xtrasolar **P**lanetary **O**bservation & **C**haracterization
  - Principal Investigator: Drake Deming (Goddard Space Flight Center)
- ❑ DIXI = **D**eep **I**mpact **E**Xtended **I**nvestigation
  - Principal Investigator: Michael A'Hearn (University of Maryland)
- ❑ **EPOCH + DIXI = EPOXI**



## What is EPOCH?

- ❑ Mission of Opportunity with non-interference requirement with DIXI
- ❑ Data was collected during cruise to DIXI comet
- ❑ Photometric investigation of star systems with known transiting hot-Jupiters



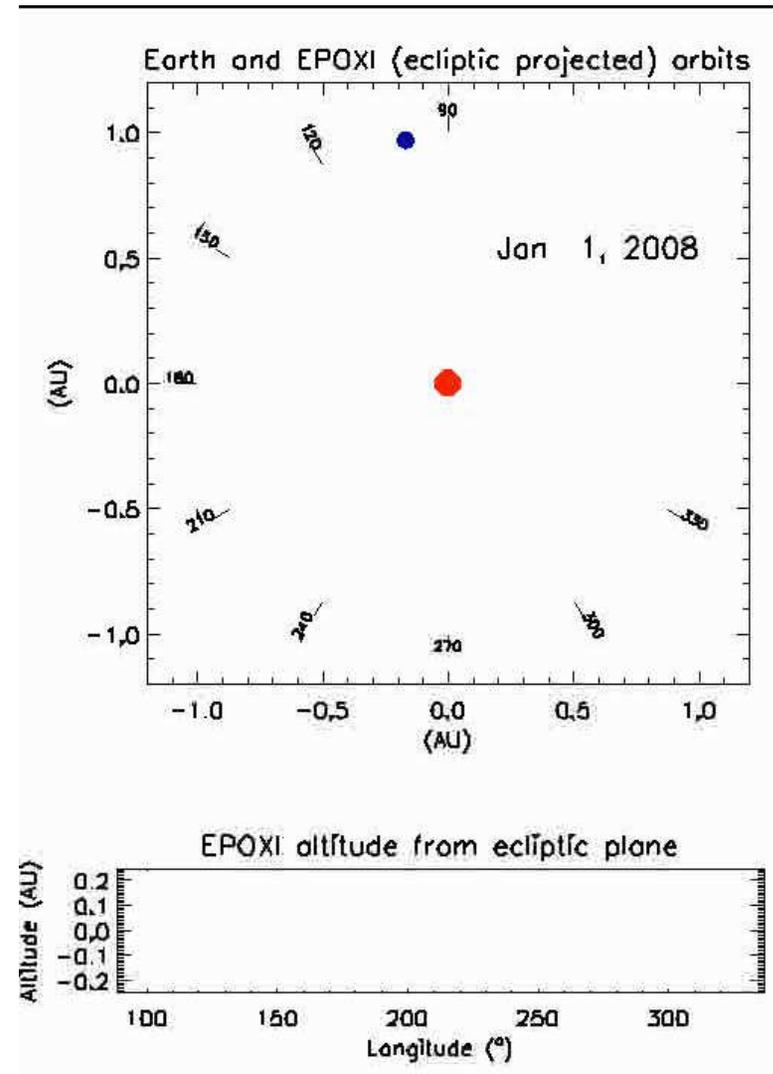
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# Operations Strategy

- ❑ Low-cost
- ❑ Low-risk
  - No risk to primary science (DIXI)
- ❑ Continuous imaging for several days at a time
- ❑ Accommodate a variable DSN schedule
- ❑ Heavily reliant on automation
- ❑ Flexible sequenced commanding and limited real-time operations
- ❑ Reusable on-board blocks to perform repetitive tasks with variable timing

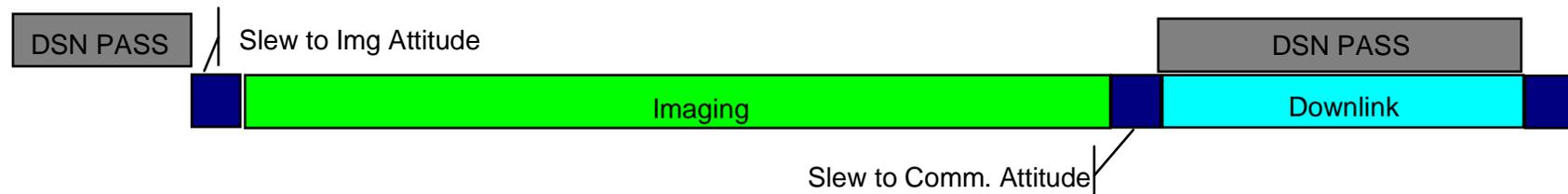
## Order of Operations

- ❑ Spacecraft orbit  $\Rightarrow$  targets
- ❑ Targets  $\Rightarrow$  Keep Out Zones (KOZs) (transits & eclipses)
- ❑ KOZs  $\Rightarrow$  DSN schedule
- ❑ DSN schedule  $\Rightarrow$  Sequences



## Operations Technique

1. Turn to target
2. Image
3. Turn to Earth-point
4. Downlink
5. Repeat



## What are the Risks?

- ❑ Risk to spacecraft

- SAFE!

- ❑ Risk to science

- LOSS OF DOWNLINK
- POINTING STABILITY

# Solving Potential Problems

## Pros

- Preempt issues before they materialize
- Minimize interruption to science collection
- Could create better quality science
- Could be safer for the spacecraft

## Cons

- Large initial investment in money and time
- Delays start of gathering science
- Could solve anticipated problems that do not occur
- Sacrifice flexibility in exchange for a strategy robust to unknowns

# Solving Actual Problems

## Pros

- Solve only problems experienced, not anticipated
- Start operations sooner
- Less costly

## Cons

- Sacrifice quality of data to discover a problem
- May result in interruption of science while problem is solved
- Could sacrifice science quantity to uncover a problem

## Project Identified Risks

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- ❑ Known knowns
- ❑ Known unknowns
  - Pointing instability
  - Downlink reliability
- ❑ Unknown unknowns
  - ?

## Pointing Stability

### **Risk:**

- Platform stability is not characterized over durations of days
  - Designed for comet flyby with full FOV using AutoNav, not astronomy operations using smaller FOV
  - Impactor provided structural support used for alignment of ACS hardware

### **Possible Solutions:**

- Could perform experiments to characterize
- Could create detailed models and simulation

### **Actual Solution:**

- Risk accepted based on an existing calibration data point
- Several solutions were identified that could be implemented quickly

# Transmission Reliability

## **Risk:**

- Image loss experienced during prime mission

## **Possible Solutions:**

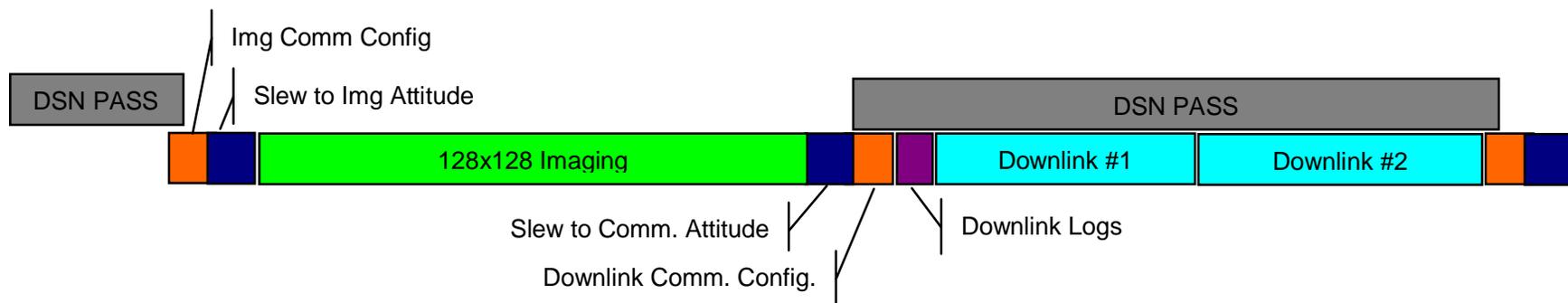
- Real-time image analysis and retransmission
- Leap-frog technique

## **Actual Solution:**

- Redundant downlink of all images

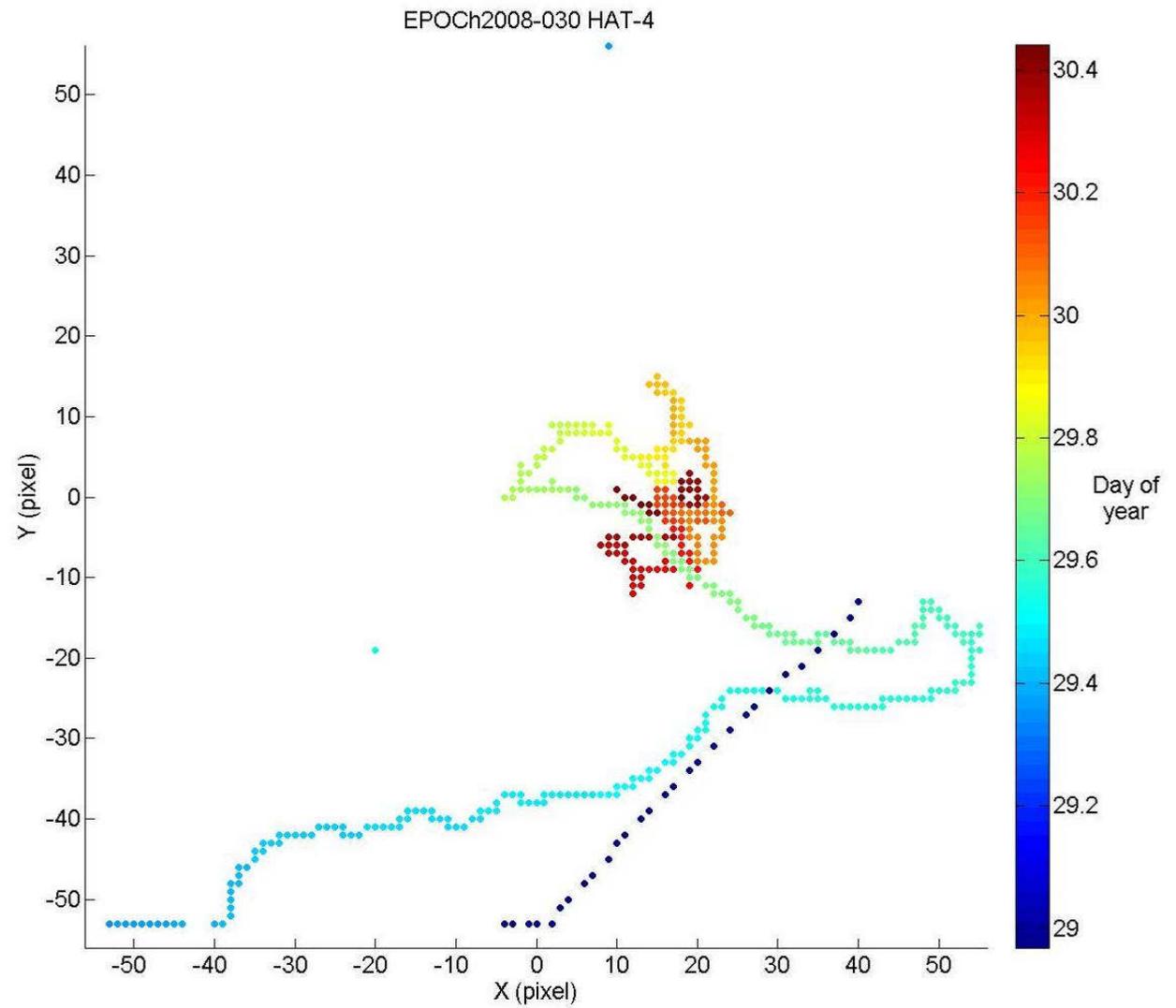
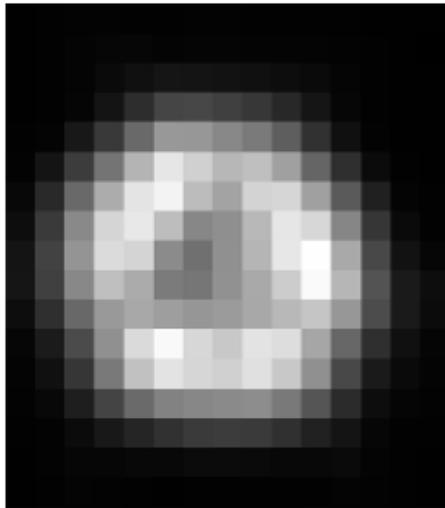
## Initial strategy

- ❑ Reusable blocks (relative-timed sequences), spawned from a master backbone sequence
  - Communication configuration for imaging
  - Slew to target
  - Image
  - Slew to communication attitude
  - Communication configuration for downlink
  - Downlink
  - Downlink x2
  - Repeat



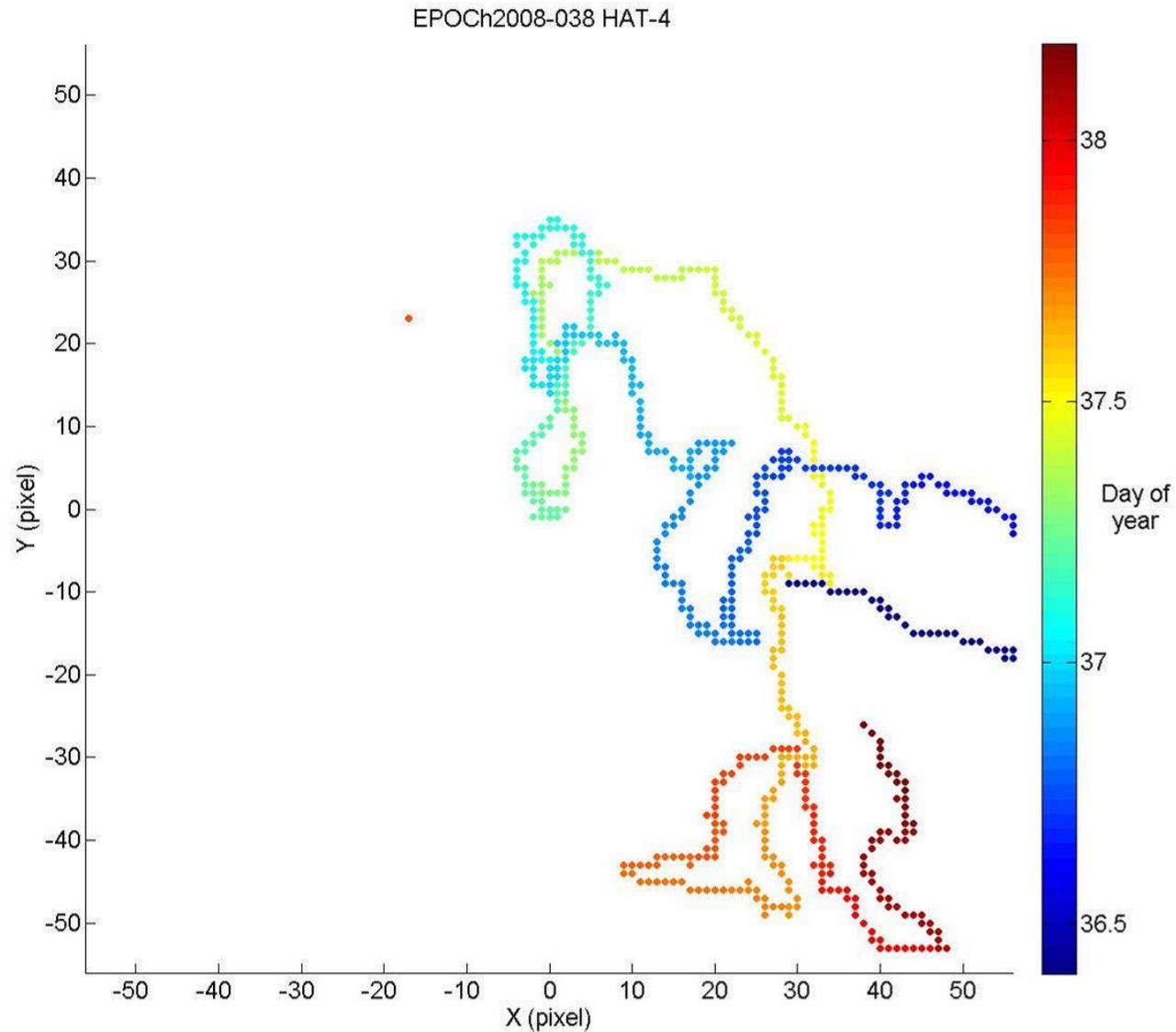
# Results

**EPOXI**

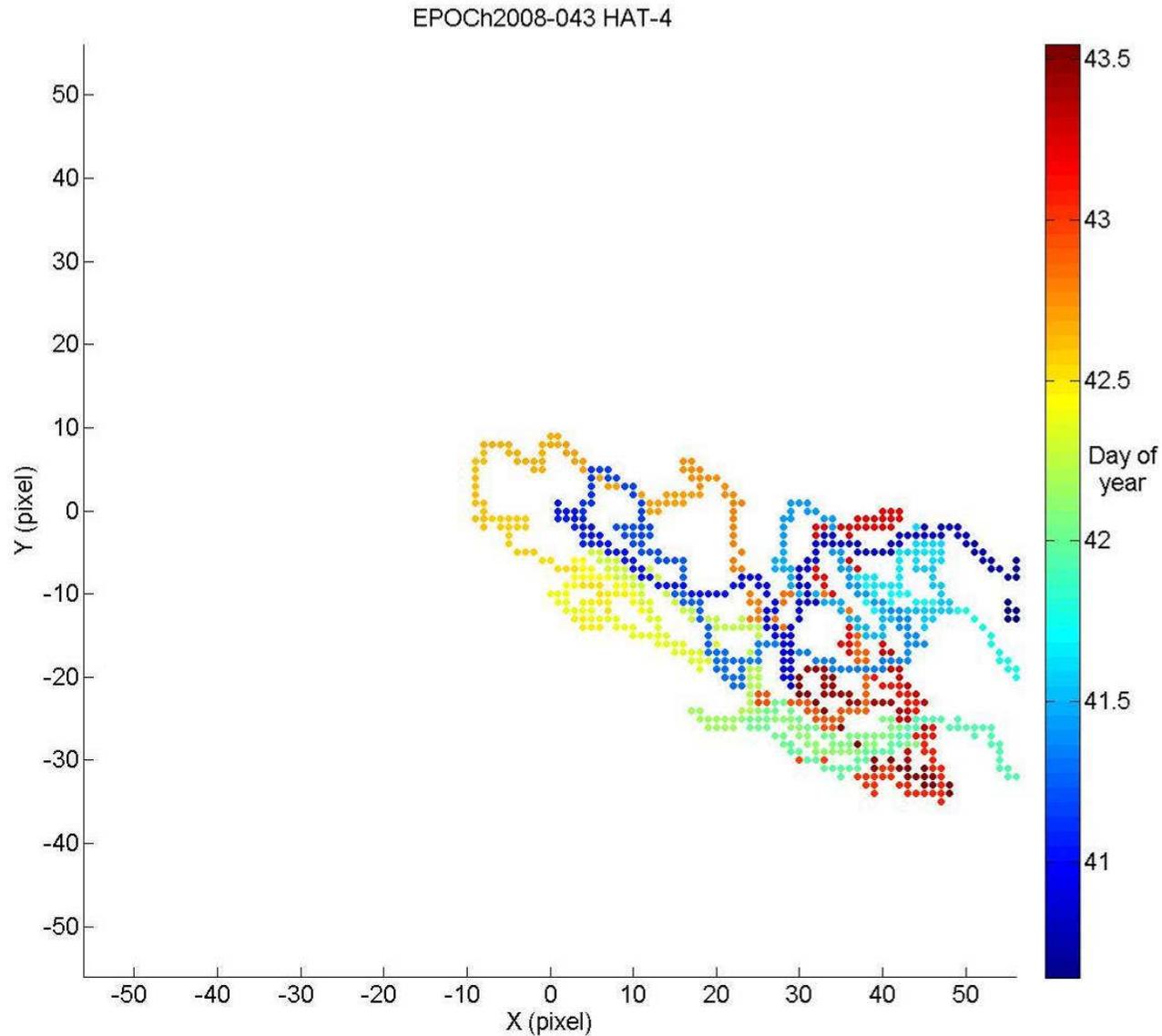


# Pointing Solutions – Pointing Offset

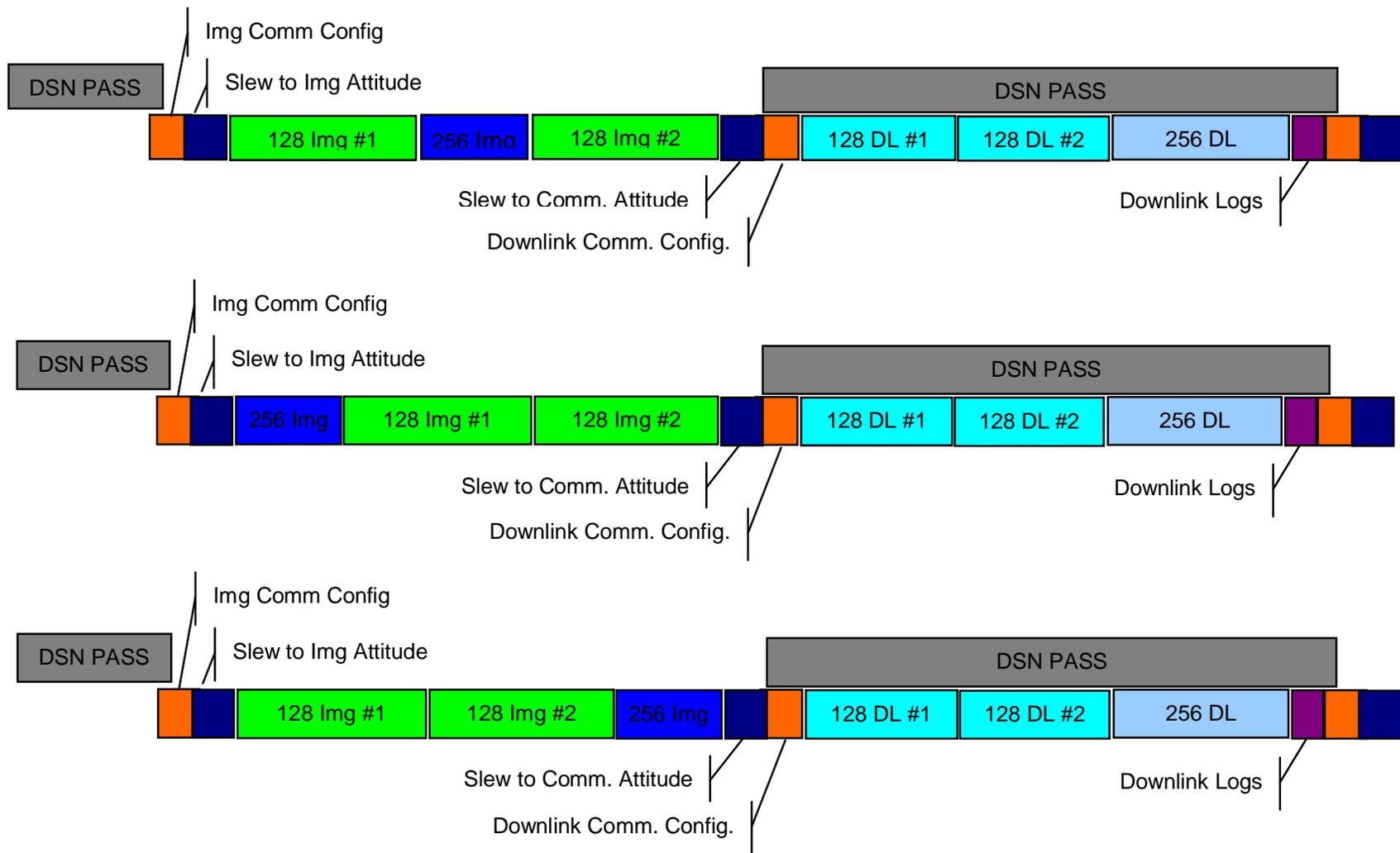
**EPOXI**



## Pointing Solutions – Gyro Bias

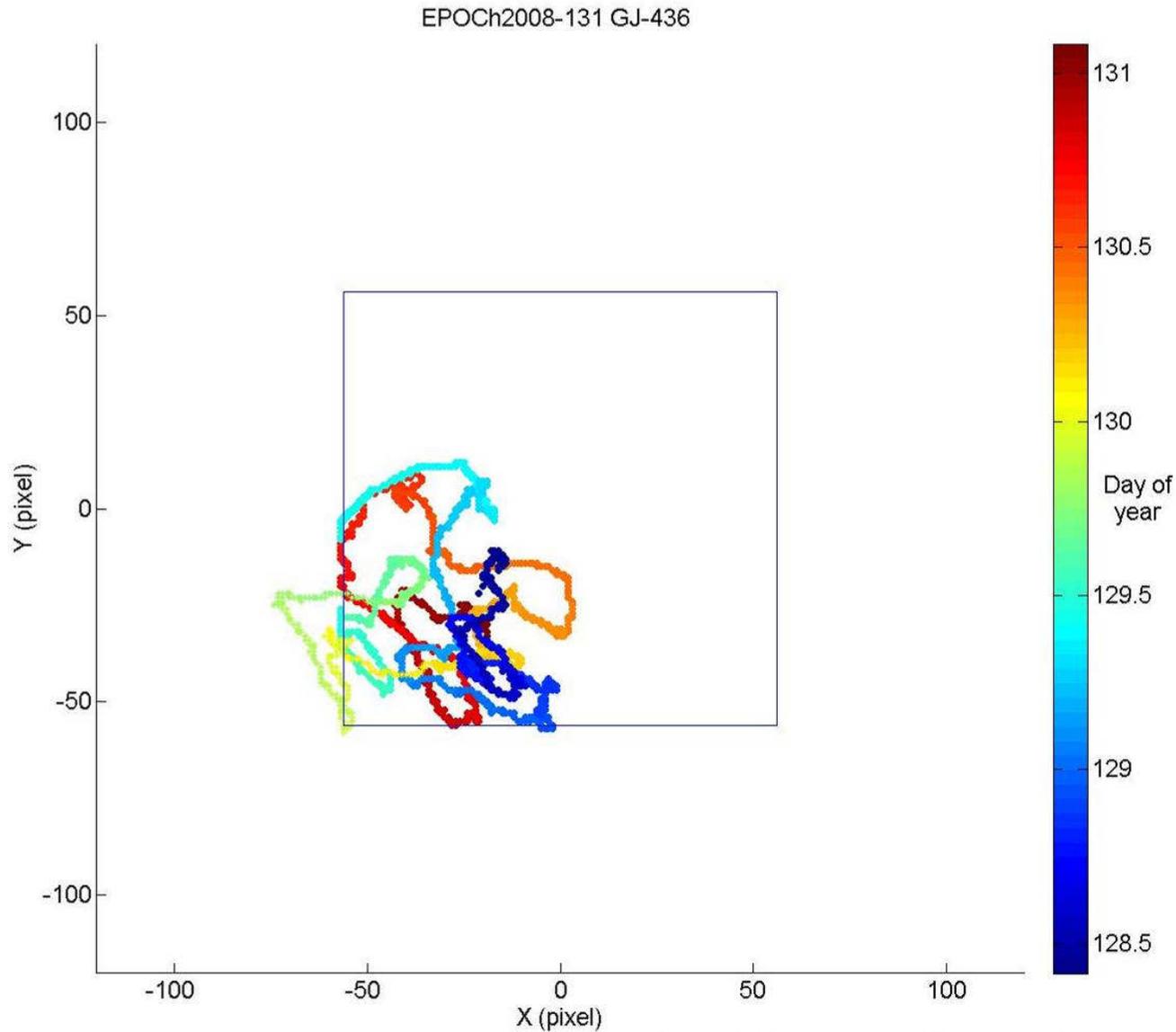


## Pointing Solutions – Hybrid Imaging



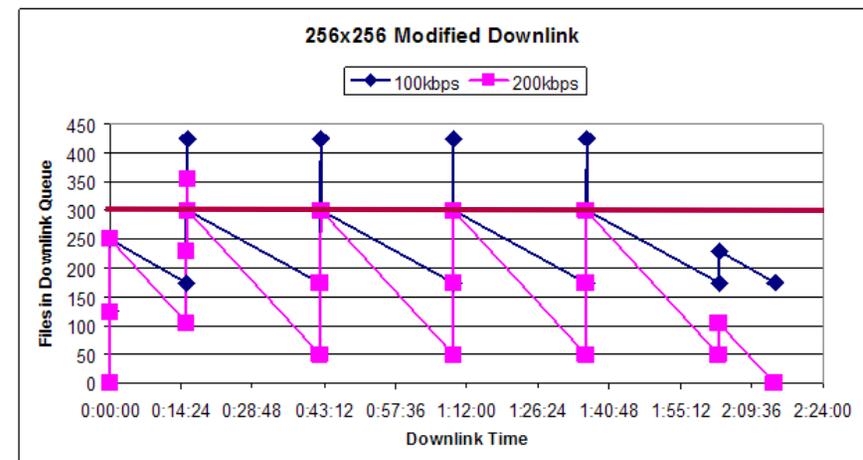
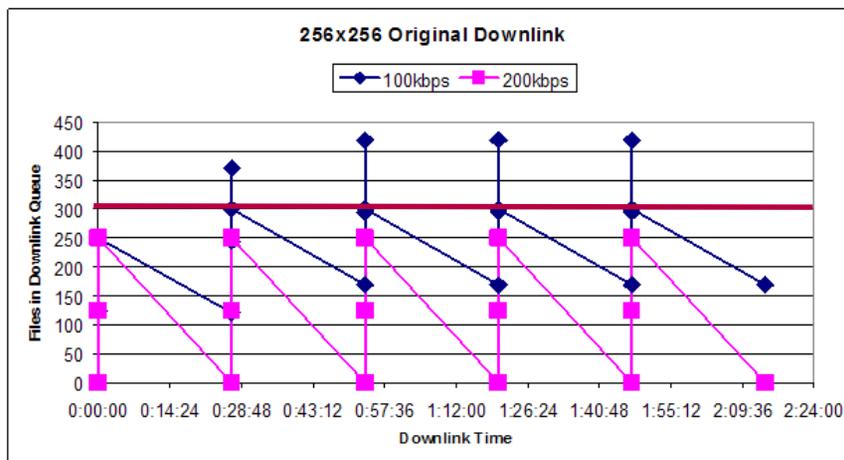
# Pointing Solutions – Hybrid Imaging

**EPOXI**



## Downlink Power Loss

- ❑ Lost 8 dB from telecom signal near perihelion
- ❑ Downlink had to get all 256x256 images:
  - Twice at 200kbps
  - Once at 100kbps



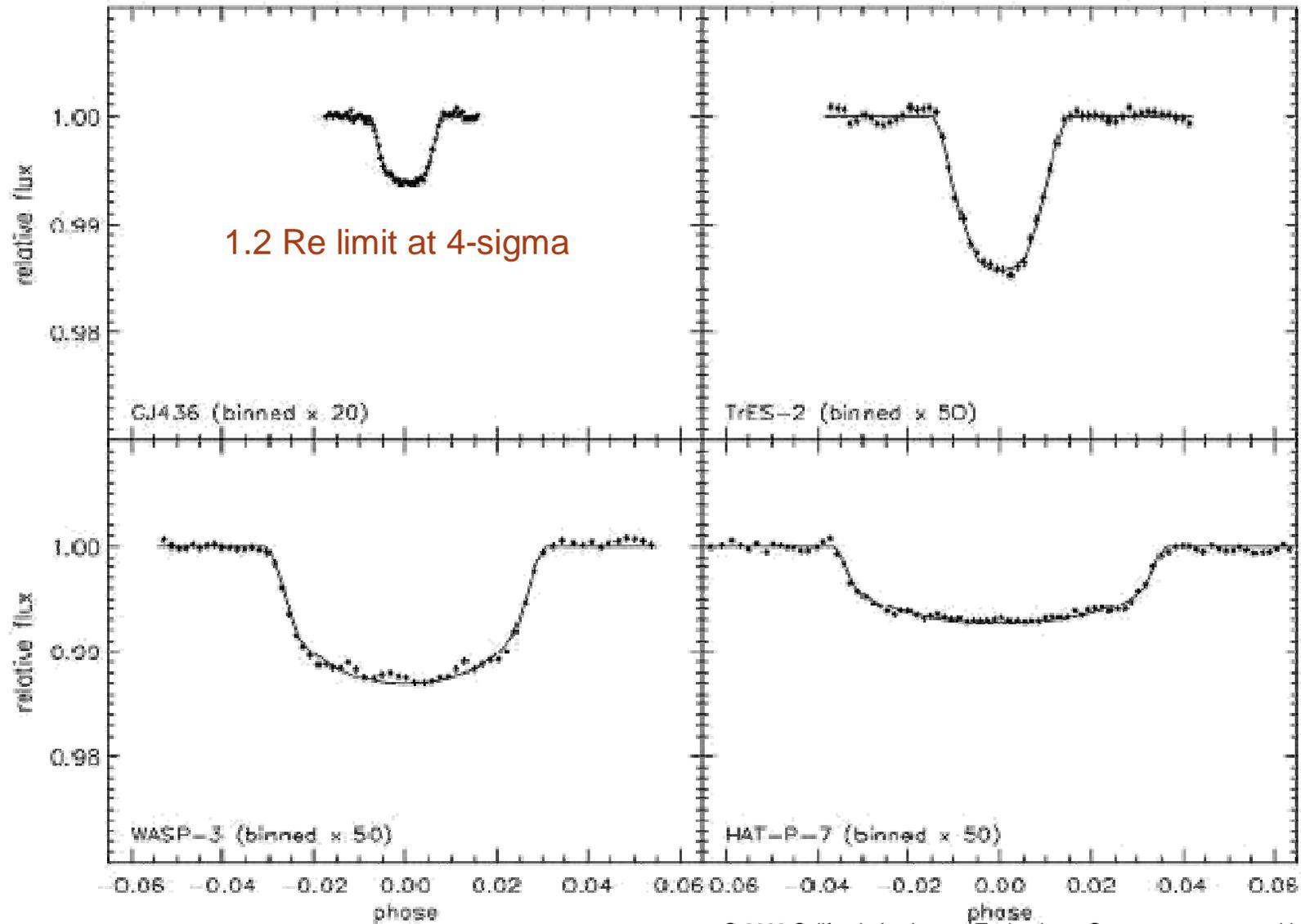
Added to Queue	1-125	251-375	501-625	126-250	376-500
100kbps received	1-130	131-260	261-390	391-445	591-625
100kbps lost				445-500	6-125
200kbps received	1-250	251-500	501-625	126-375	376-625
			1-125		

Added to Queue	1-125	501-625	376-500	126-250	251-375	196-250
100kbps received	1-75	76-125	326-375	576-625	451-500	201-250
100kbps lost		126-250	1-125	501-625	376-500	256-375
200kbps received	1-125	271-375	146-195	75-125	576-625	451-500
	251-270	501-625	376-500	126-250	251-375	320-375
		126-145	1-75	501-575	376-450	

## Results - Operations

- ❑ 198,434 images taken
- ❑ 192,624 images received
  - Image losses due to DSN short DSN tracks with the modified downlink strategy
- ❑ 172,209 photometric images
  - Non-photometric images due to cosmic rays, image smearing, and pointing errors
- ❑ ACS recharacterization would have delayed start of operations, losing more images than were lost to pointing errors
  - Degraded science is better than no science – still held to success criteria
  - Some of the degraded science was sufficient to meet success criteria
- ❑ Telecom issues would have broken any strategy that was built before the issue was discovered

# Results - Science



## Results - Science

- GJ-436 Neptune sized (~4 Earth radii)
- Orbit period 2.6 days
- No “Hot-Earths” with orbit less than 7 days

