

Oct 4, 2011



# Keeping an Eye on the Space Shuttle During Reentry

2011 NASA LaRC Colloquium and Sigma Lecture Series



*Hypersonic Thermodynamic  
Infrared Measurements*

**HY**personic: Mach 5+

**T**hermodynamic: the relationship between heat (thermo) and work (dynamic)

**I**nfra-**R**ed: electromagnetic radiation with a wavelength longer than that of visible light

**M**easurement



# Space Shuttle Re-entry



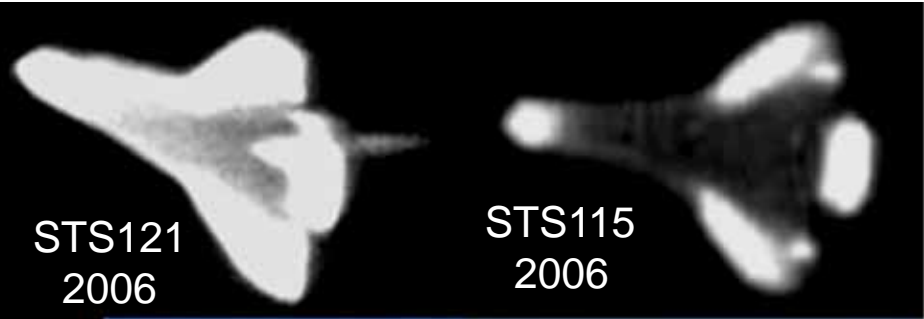
- It's fast! (~18,000 mph or 26,000 ft/sec)
- It's hot! (peak temperatures ~2,000-3,000 deg F)



STS114  
2005



STS121  
2006



STS115  
2006



2009

### Heating up Discovery's heat shield

Discovery will plunge back through Earth's atmosphere with a built-in "speed bump" on one of its thermal tiles. The quarter-inch protuberance will increase temperatures to simulate conditions NASA's next-generation Orion space capsules will encounter during atmospheric re-entries.

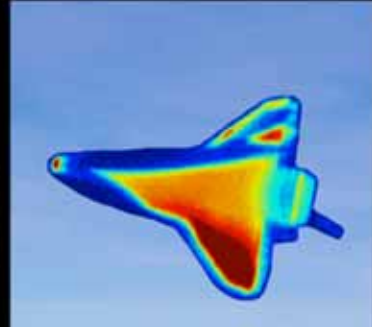


- 1 The "speed bump" will disrupt airflow and induce turbulence that will increase re-entry heating.
- 2 The tile and others downstream from it are equipped with sensors to capture temperature data.
- 3 A Navy aircraft with a long-range infrared camera will fly below the shuttle's flight path to monitor heating on the underside of the orbiter. Imagery and sensor data will guide engineers designing Orion's heat shield.

Because of Orion's geometry, its tiles will be subjected to re-entry temperatures up to 3,400 degrees Fahrenheit, about 500 degrees higher than the shuttle at re-entry.

NASA expects the 4-inch-long "speed bump" to induce turbulent airflow at Mach 12 to Mach 14 as the orbiter soars over the Gulf of Mexico.

Source: NASA. The Boeing Co. reprinted by James Dean, FLORIDA TODAY. ©2009. Debra Lee, FLORIDA TODAY.



**Success Criteria:**  
To obtain spatially resolved infrared imagery that will provide a quantified surface temperature map of the Shuttle during hypersonic re-entry



2007



2009



2007



2009



2009



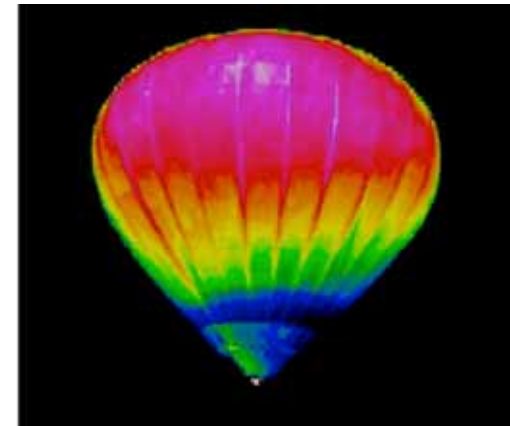
2008



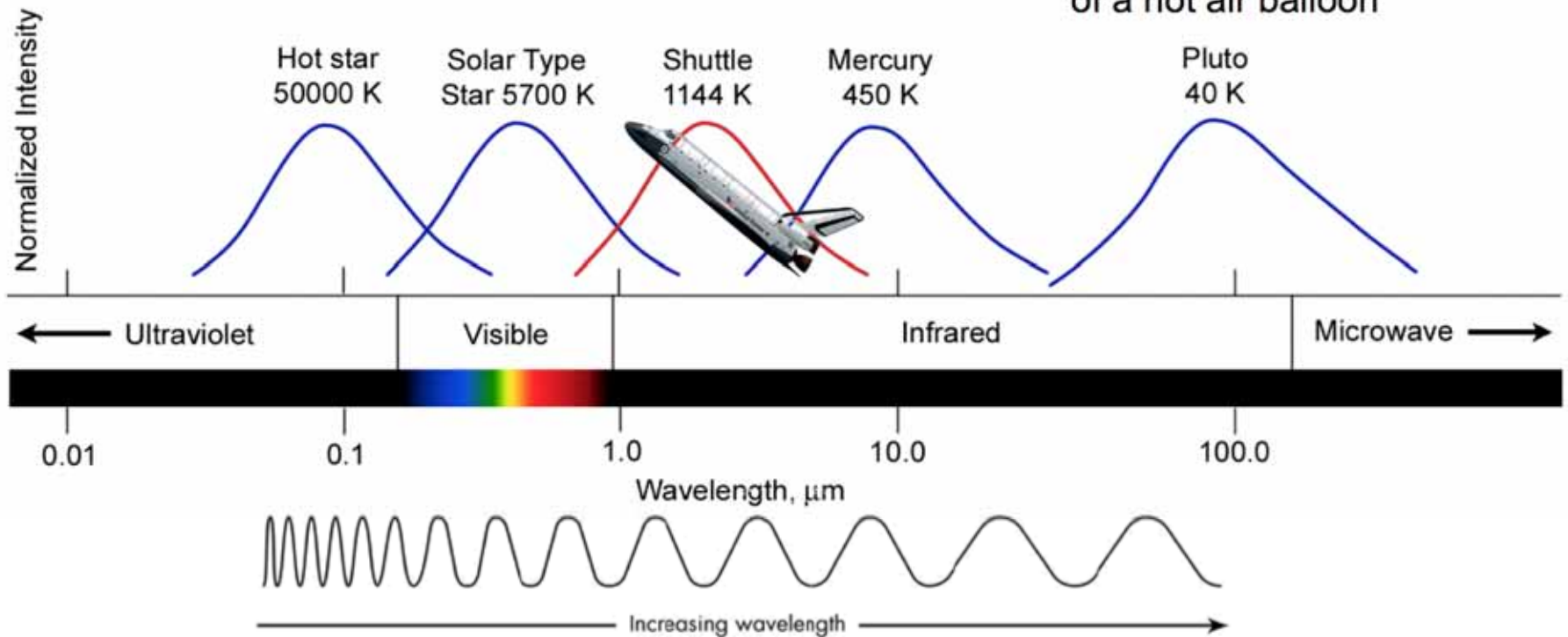
2007

# What is an Infrared Camera?

Similar to a common camera that forms an image using *visible* light, an infrared camera is a device that forms an image using *infrared* radiation



False color thermal image of a hot air balloon





# SpaceX C1 Mission

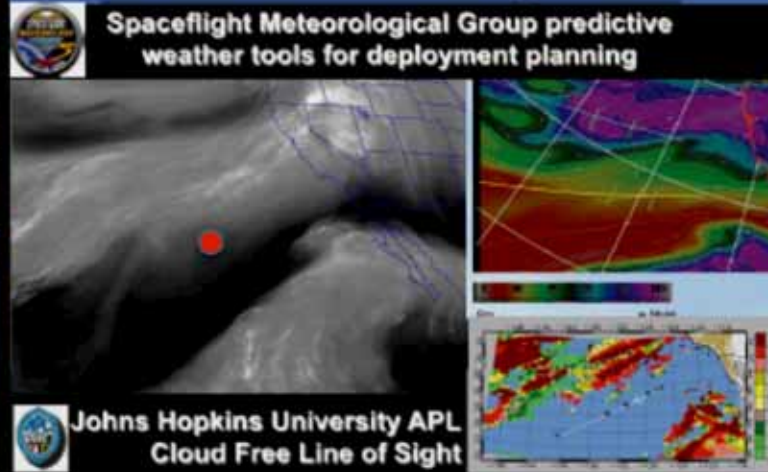
HYTHIRM: Hypersonic Thermodynamic Infrared Measurements



## HYTHIRM Operations



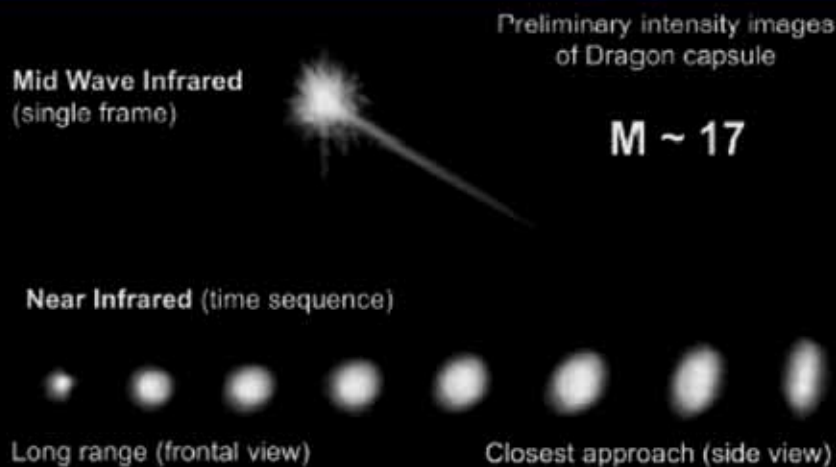
## Weather Briefings



## Reentry 12-08-10



## HYTHIRM Infrared Imagery



December 8, 2010

POC's: [Thomas.J.Horvath@nasa.gov](mailto:Thomas.J.Horvath@nasa.gov) (PI); [Robert.V.Kerns@nasa.gov](mailto:Robert.V.Kerns@nasa.gov) (PM)

Sponsors: NASA SSPO/Commercial Crew & Cargo

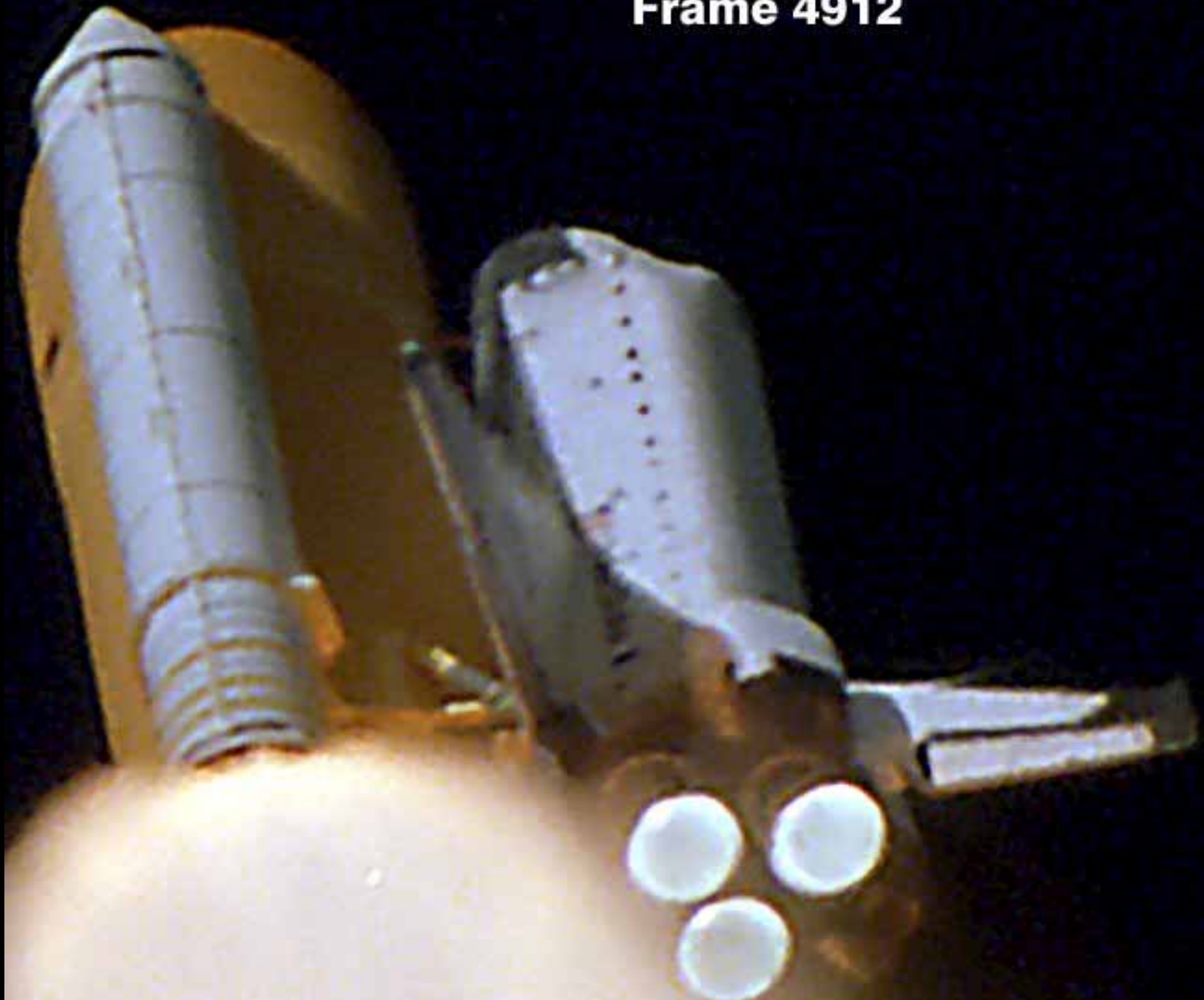
## Why Do We Want to Image the Shuttle with Infrared Cameras?

Break up of Shuttle  
Columbia over Texas



Memorial outside NASA  
Langley Research  
Center

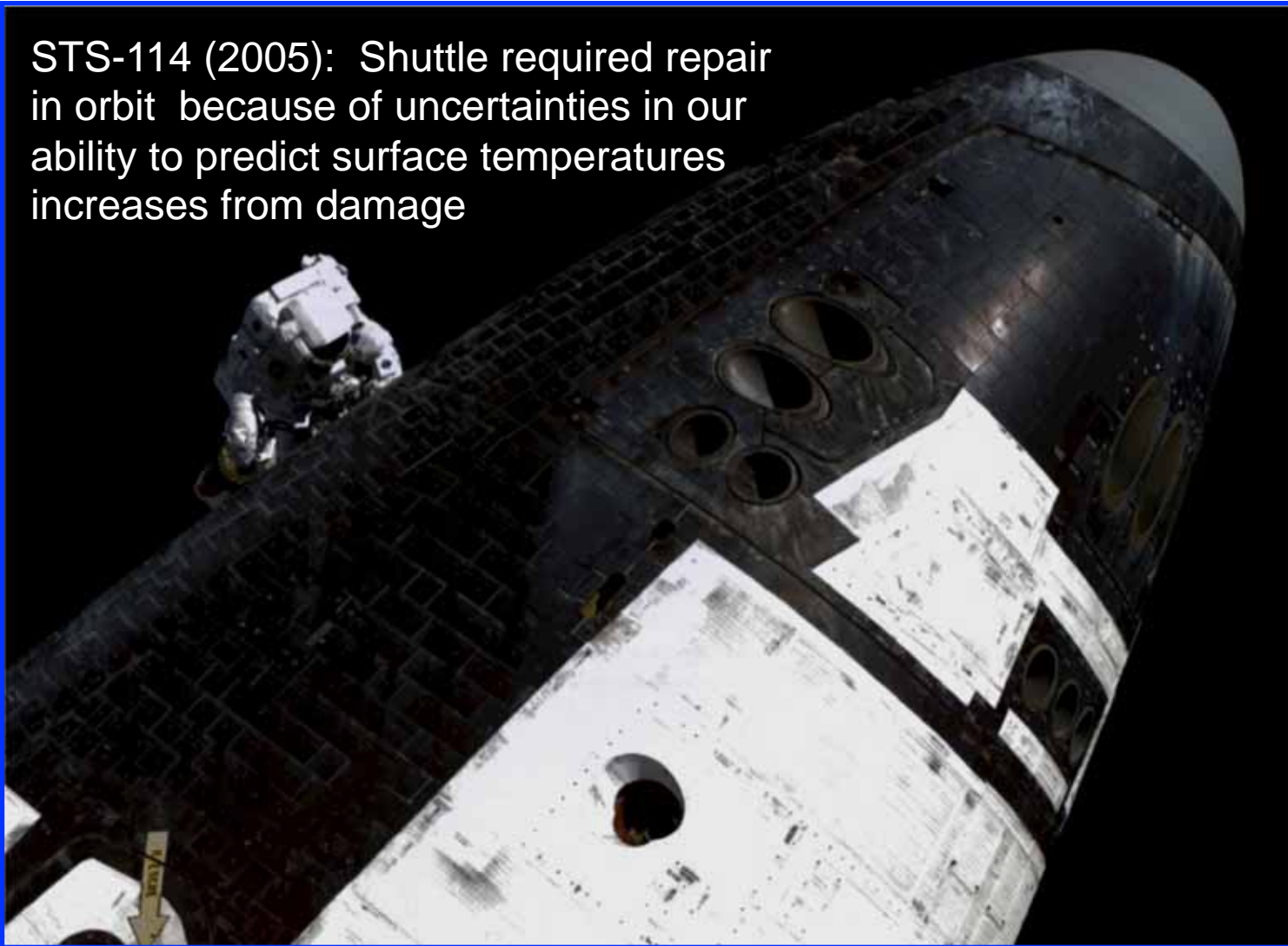
Frame 4912



# What are the Implications of Damage?

Inability to accurately predict thermal environments has design and operational impacts including potential loss of vehicle/crew...

STS-114 (2005): Shuttle required repair in orbit because of uncertainties in our ability to predict surface temperatures increases from damage



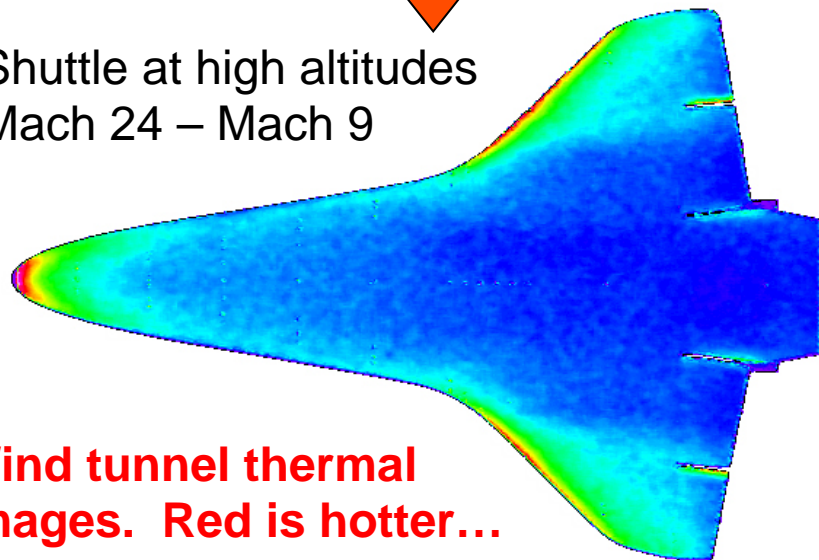


# Laminar Flow

# Turbulent Flow



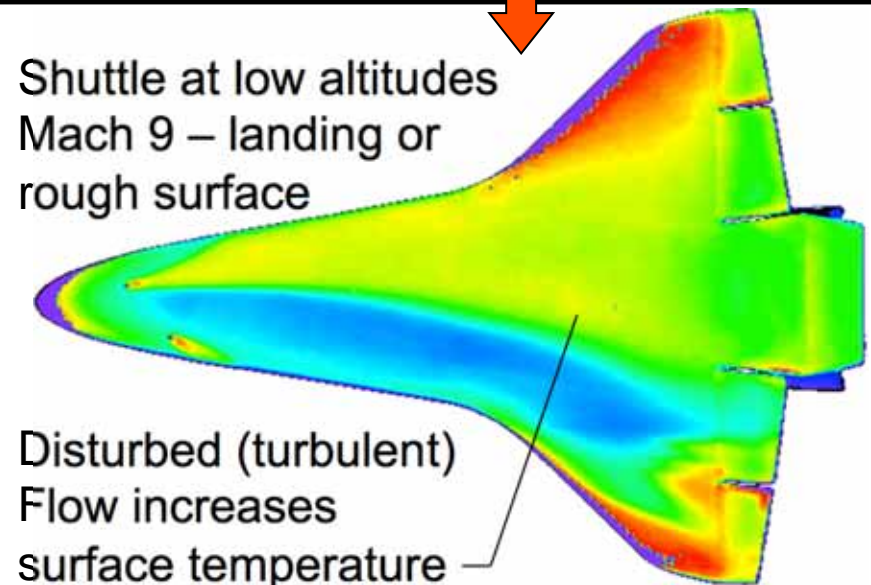
Shuttle at high altitudes  
Mach 24 – Mach 9



**Wind tunnel thermal images. Red is hotter...**



Shuttle at low altitudes  
Mach 9 – landing or  
rough surface



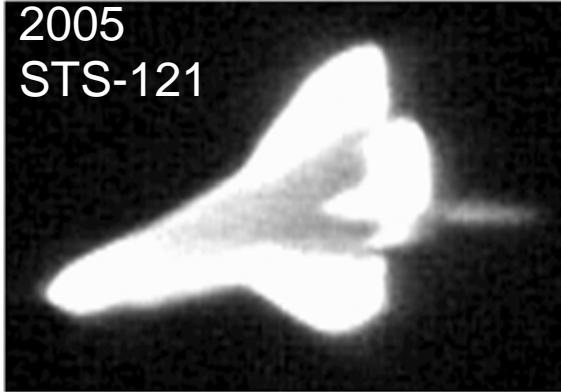
Disturbed (turbulent)  
Flow increases  
surface temperature

Sensor  
Characterization

# The IR Sensor “Challenge”

198:13:01:07.25 GMT

2005  
STS-121

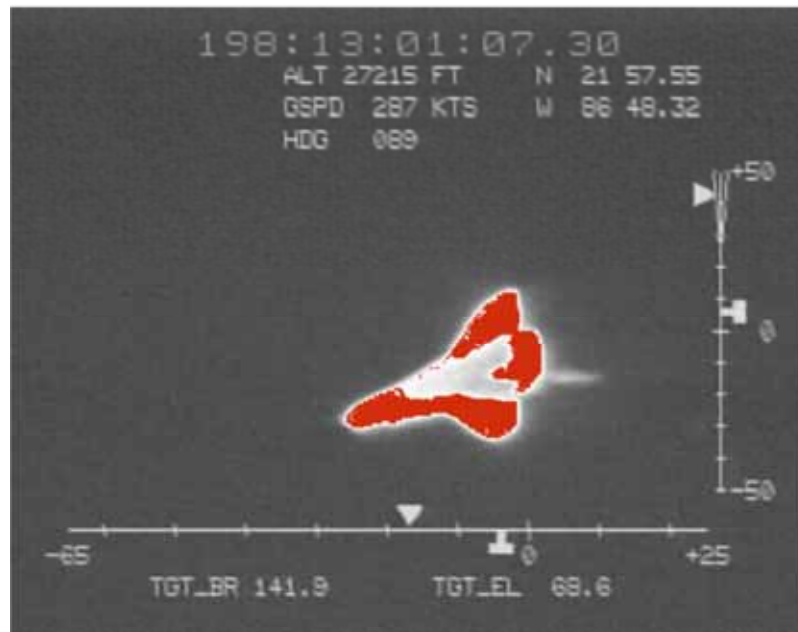


Pre-HYTHIRM  
Cast Glance legacy  
analog system  
Insufficient dynamic  
range and low  
signal-to-noise

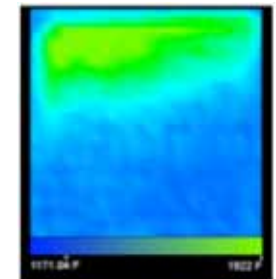


LI900 Shuttle tile array

Aerial photo



Sensor response  
quantified at Sandia Solar  
Tower tests (2008)  
Recommendation:  
Upgrade to 12 bit digital  
NIR sensor



Sensor  
Upgrades

# Sensor Improvements



Manuf.	Model	Pixel size X (um)	Pixel size Y (um)	# Pixels X	# Pixels Y	Frame Rate (fps)	Bits per pixel
Cohu	2122	5.5	6.4	768	494	30	8
Prosilica	GC1380H	6.5	6.5	1360	1024	30-84	12

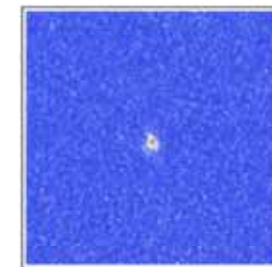


Hardware and software upgrades

## Sensor upgrade implemented (2009)

- Wider dynamic range
- Improved Signal to Noise Ratio (SNR)
- Controls for setting integration time

# Calibration

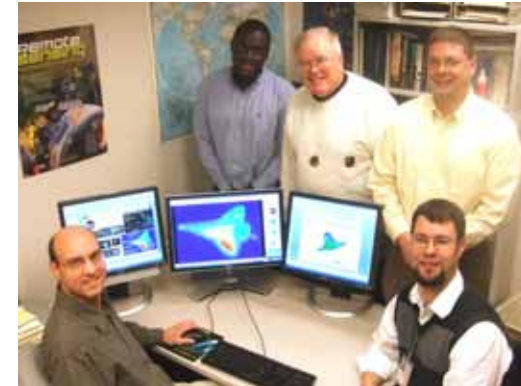
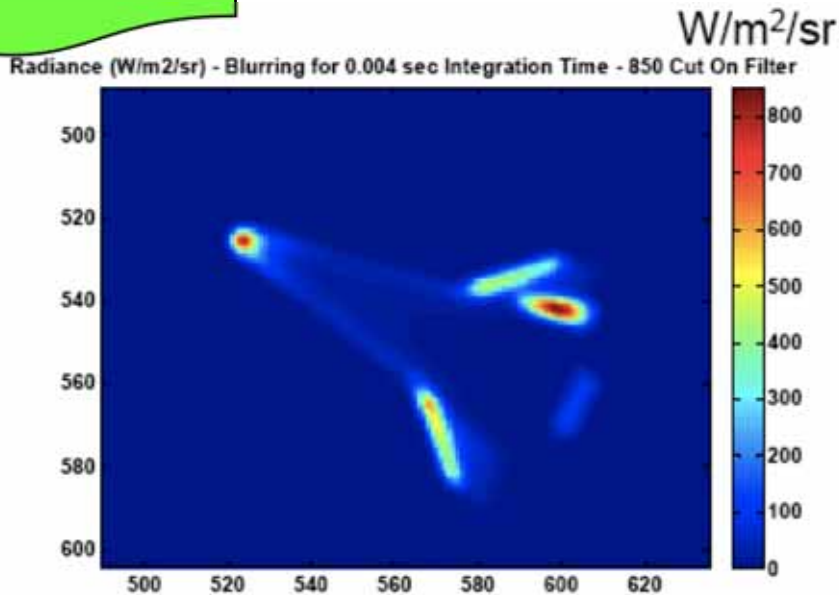


Sirius NIR  
image

- Radiometric (black bodies; stars) Radiance vs sensor response @ integration times
- Spatial (pin hole; stars; laser) characterization of image blurring
- Spectral (filters and spectral lamp) losses thru optical system

Radiance Modeling

# Pre-Flight Sensor Configuration



Simulation of real sensor response (resolution, atmospheric effects, dynamic range and integration time)

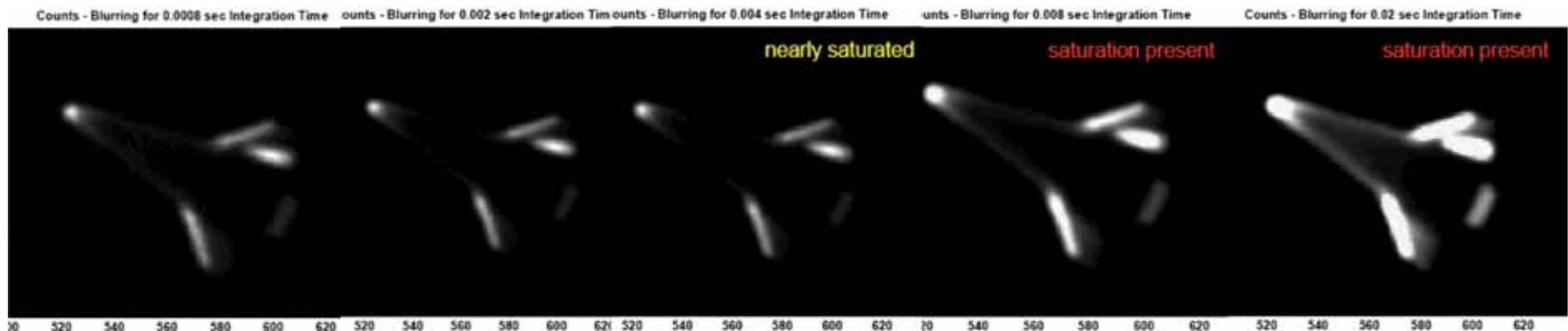
0.2 ms



Increasing exposure time



20 ms



Less blurring but...  
low signal/noise (S/N)

Higher S/N but...  
more blurring & saturation 13



# The Mission Operations "Challenge"



Mobile Aerial Reconnaissance System (MARS) deployment



A Hurricane in the Pacific!

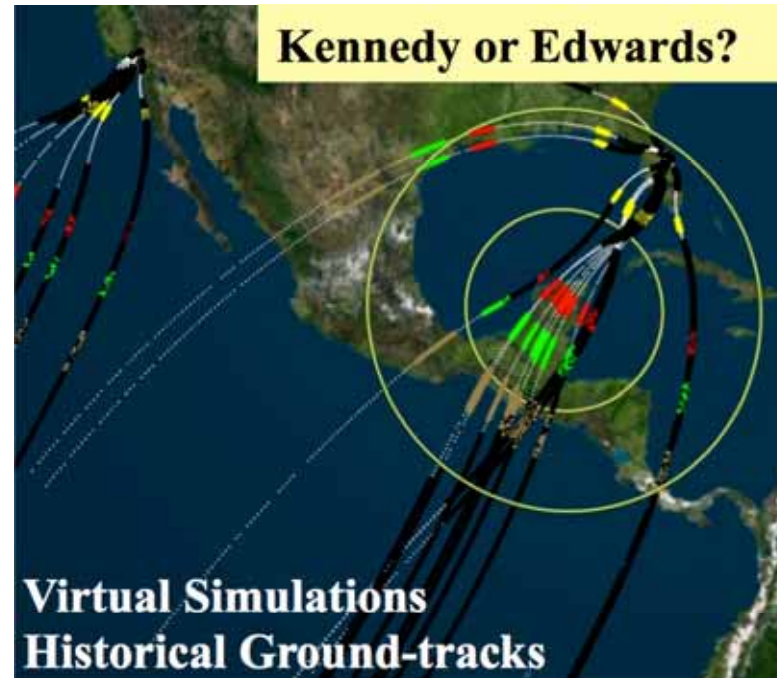


HYTHIRM Mission Operations Team

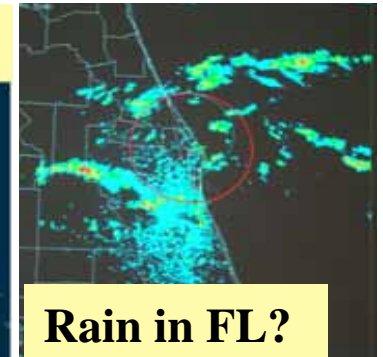


Navy NP-3D Orion

Kennedy or Edwards?



Virtual Simulations  
Historical Ground-tracks



Rain in FL?

Spaceflight  
Meteorology  
Group



Cast Glance Personnel &  
VX-30 Squadron



# Directing the Show...



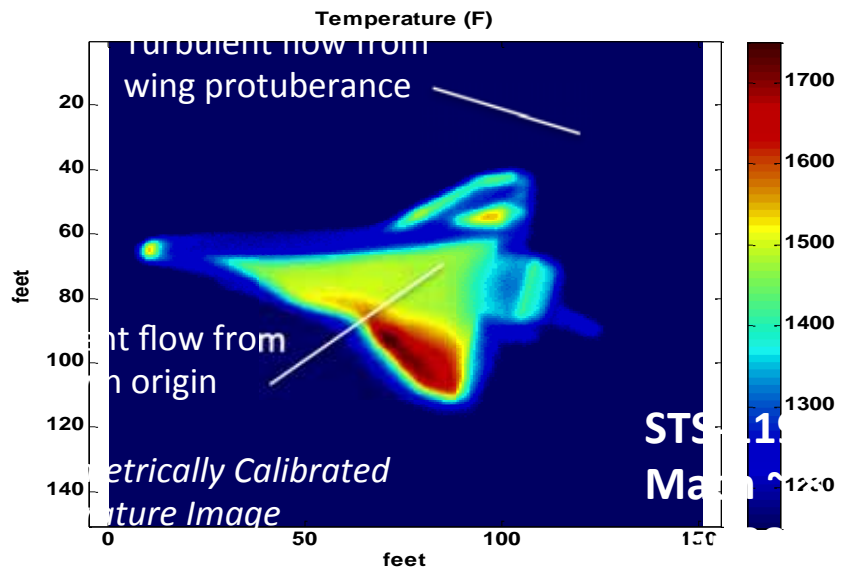
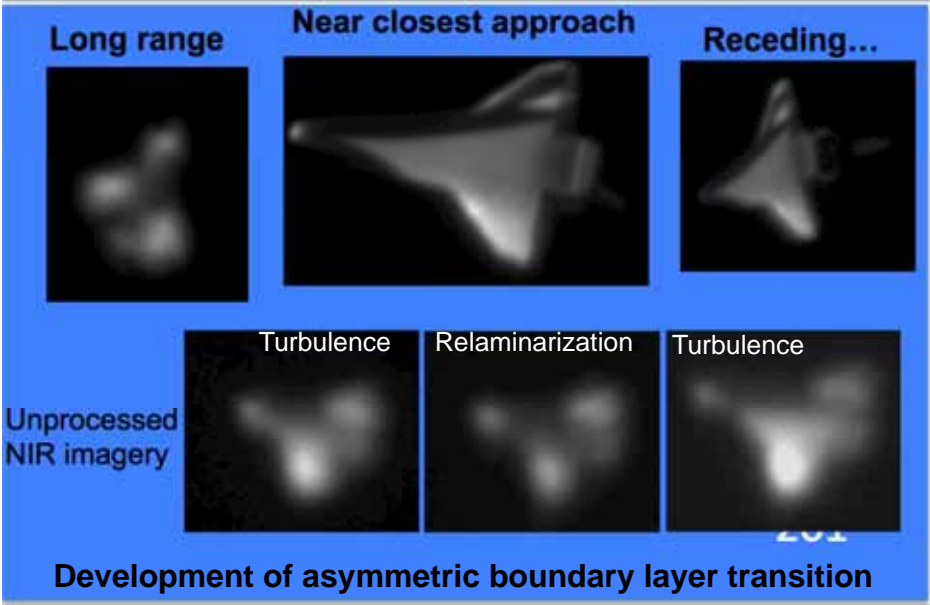
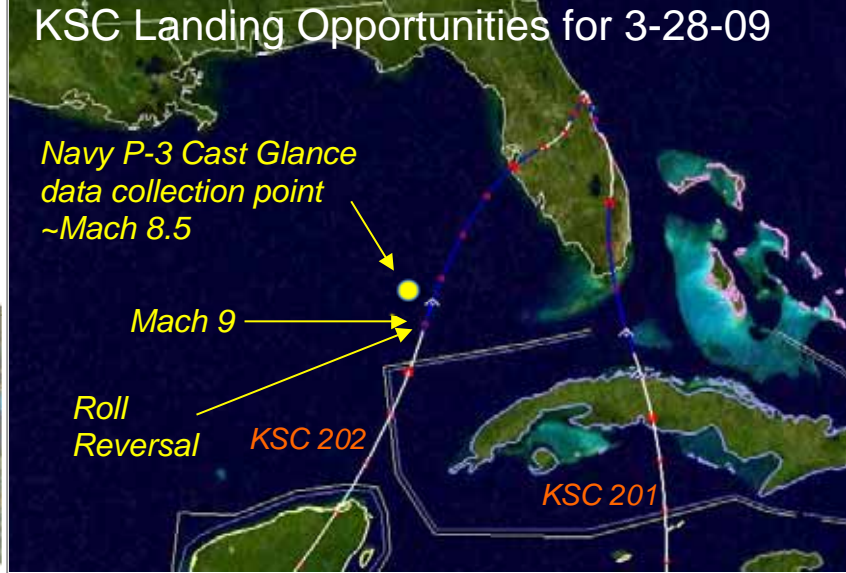


# HYTHIRM

Hypersonic Thermodynamic Infrared Measurements



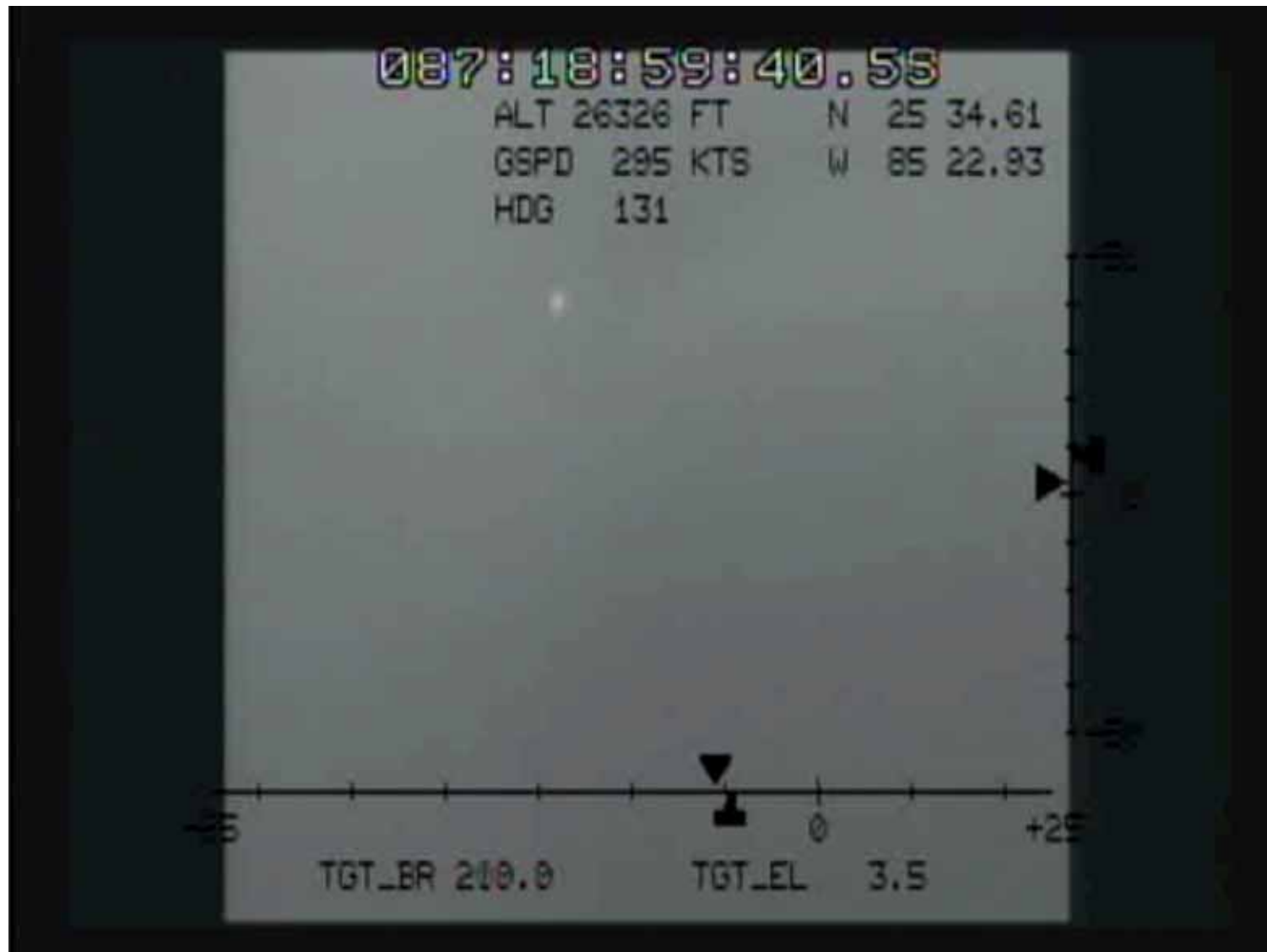
**STS-119 success criteria:** To obtain spatially resolved infrared imagery during a flight experiment that will provide a quantified surface temperature map of the Shuttle during hypersonic re-entry





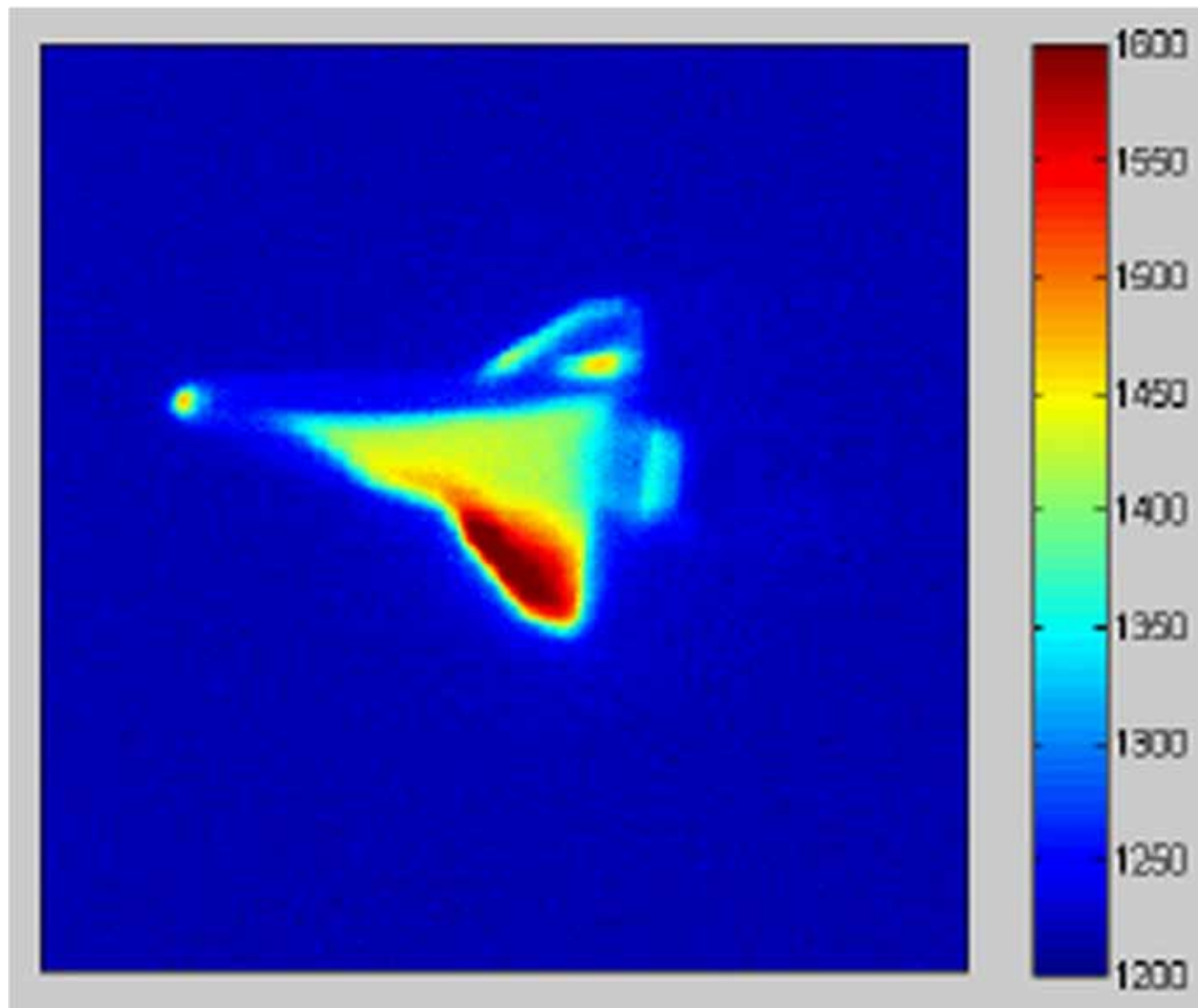


# Image Acquisition from the Navy P-3 Aircraft



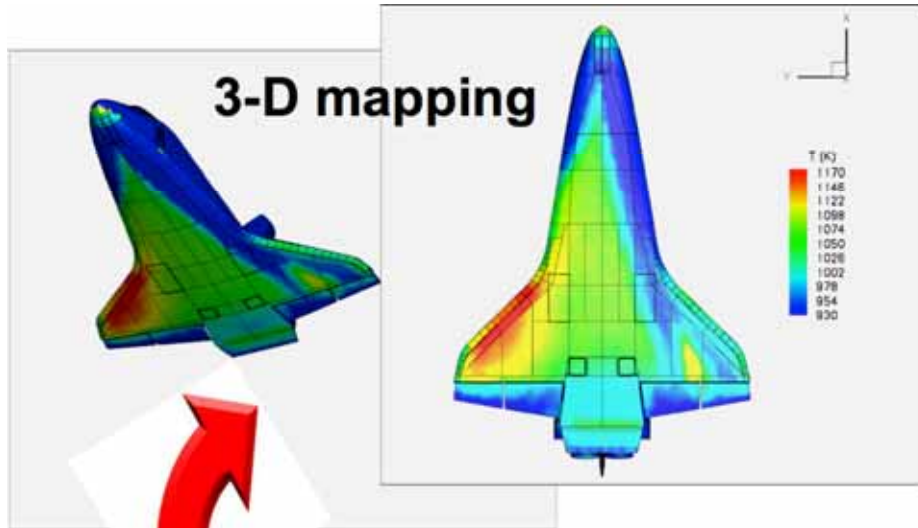


# Orbiter Surface Temperature (deg F) from Radiometric Calibration

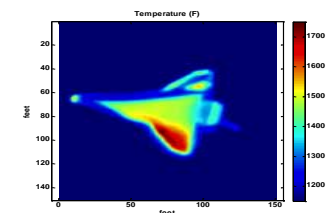
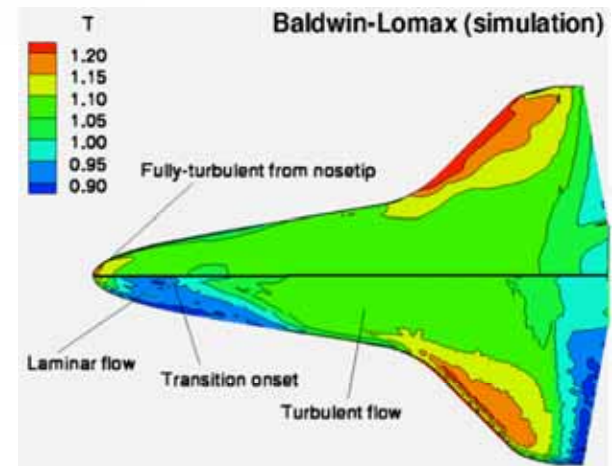




# Making Our Design Tools Better



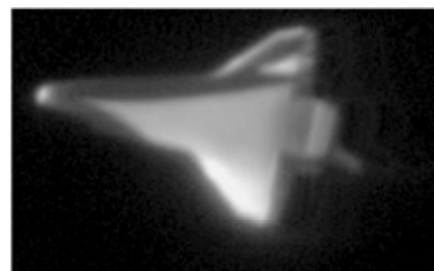
## Comparison to modeling Tools



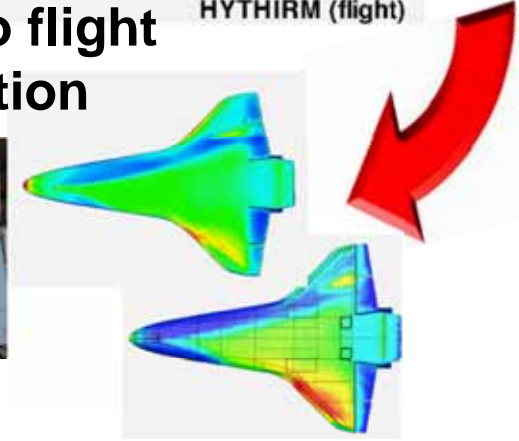
## 2-D processed data

## Ground to flight extrapolation

HYTHIRM (flight)



## Thermal data collection





# Navy Water Survival Training!





# Flying on the P-3!





# Front Page News!



Wednesday  
March 9, 2011

# Taco Times

50¢  
Two Sections  
50th year, No. 9  
www.perrynewspapers.com

Serving the Tree Capital of the South Since 1861

### Dean seeks early start to 2011 scallop season

County Commissioner Dean seeks an early start to the 2011 scallop season. The season typically begins in late May or early June, but weather conditions have been favorable for an earlier start. Dean is looking for support from the community and the fishing industry to begin the season as soon as possible. The scallop fishery is a vital part of the local economy, and an early start would benefit many families who rely on it for their livelihood.

### Bringing 30-plus new jobs

## Company looks to locate plant here

A local company is looking to bring 30-plus new jobs to the area by locating a new plant here. The company, which has been successful in other markets, is seeking a location with good infrastructure and a skilled workforce. The proposed plant would provide a significant boost to the local economy and create many opportunities for residents. The company is currently in the planning stages and expects to announce a final location soon.



## NASA keeps an eye on the sky over Perry-Foley Airport

By MARK VIOLA  
Staff writer

Taylor County could play a role today (Wednesday) in helping to develop the next generation of human space flight.

A National Aeronautics and Space Administration (NASA) team arrived at the Perry-Foley Airport Tuesday in advance of the projected return of Space Shuttle Discovery to Earth today.

The team is part of a project called the Hypersonic Thermodynamic Infrared Measurement (HYTHIRM), which will measure the heat produced by the shuttle's re-entry, said Lawrence Taylor with NASA's Langley Research Center in Hampton, Va.

The team is one of two deployed in Florida, with the other in the Tampa/St.

Petersburg area, Taylor said. The first landing opportunity will be in orbit 202 at 11:58 a.m. today, which would take Discovery over the Tampa area.

Should weather or another delay force the shuttle to wait until the next orbit, re-entry would take place about 1:34 p.m. with a trajectory over Taylor County.

Although Taylor said residents will not be able to see the shuttle here, if the winds are right, they will be able to hear the sonic boom as it passes.

The team should be able to pick up the shuttle while it is traveling at Mach 10, or 10 times the speed of sound, and follow it through Mach 6, Taylor said.

The equipment they have on site at the airport includes

— Please see page 6

A team from National Aeronautics and Space Administration (NASA) team will be at Perry-Foley Airport today (Wednesday) to monitor Space Shuttle Discovery's return to Earth. The team has an infrared camera attached to telescopes to measure the heat produced by the shuttle's re-entry, data which will be used in the development of future spacecraft.

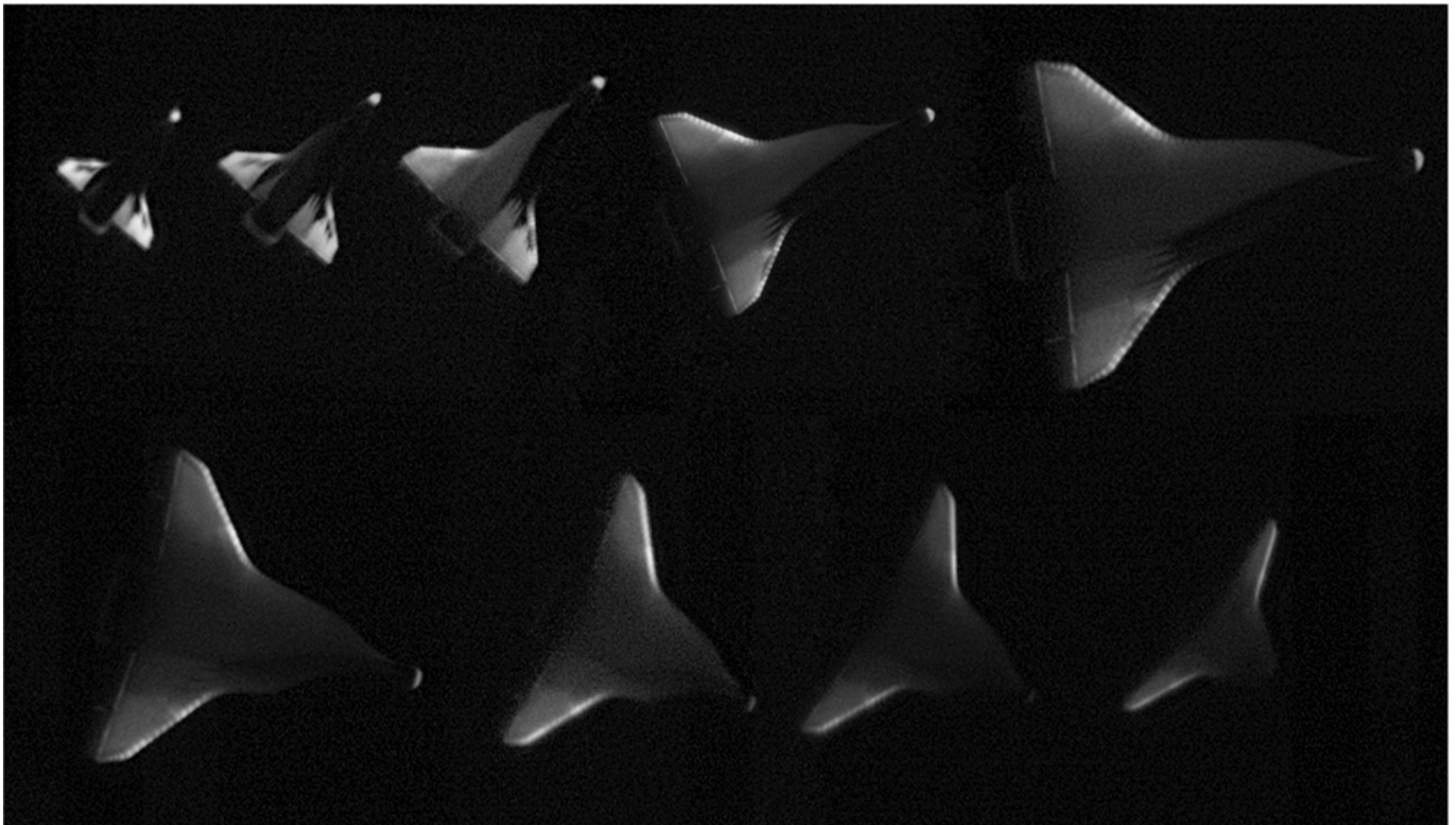


# Lots of Public Interest!





# The Last Flight of Endeavour STS-134 June 1, 2011





# Future Vision...

A portfolio of sensor, optical and image processing investments which will collectively enable more accurate, higher resolution real time flight data...

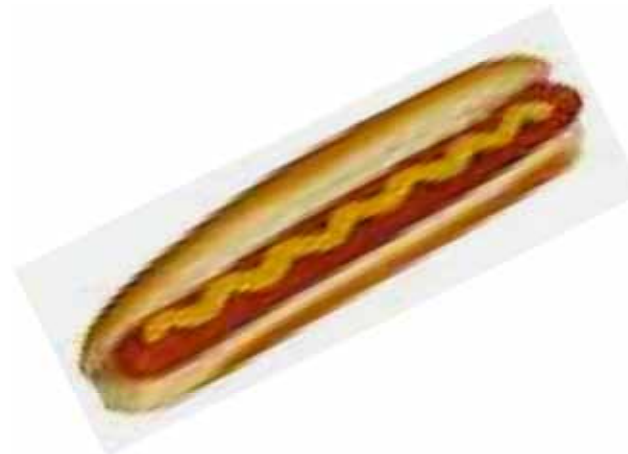




# Public Out Reach – NASA EDGE



What does mustard  
have to do with  
HYTHIRM?



**BACK UP**

Click to return to previous slide



# Navy (VX-30) P-3's

- **Imaging:**

- Visual, NIR, SWIR, MWIR, Spectral
- 210" NIR, 160" color, 80" NIR, 15" SWIR, 80" high speed DV, 40" NIR, aft MWIR

- **Telemetry:**

- BH-340, 341 have identical phased array telemetry antennas
- Beam steered (port side); 120 deg az, 80 deg elev
- Receive in S-band, 2.2 to 2.4 GHz; line of site
- Can demodulate and record SOQPSK (Space-X requirement 350kbps)
- Can be reconfigured for imaging + telemetry (non optimal config for imaging)

Imaging:  
BH-300 (shown) and BH-340



Telemetry:  
BH-341

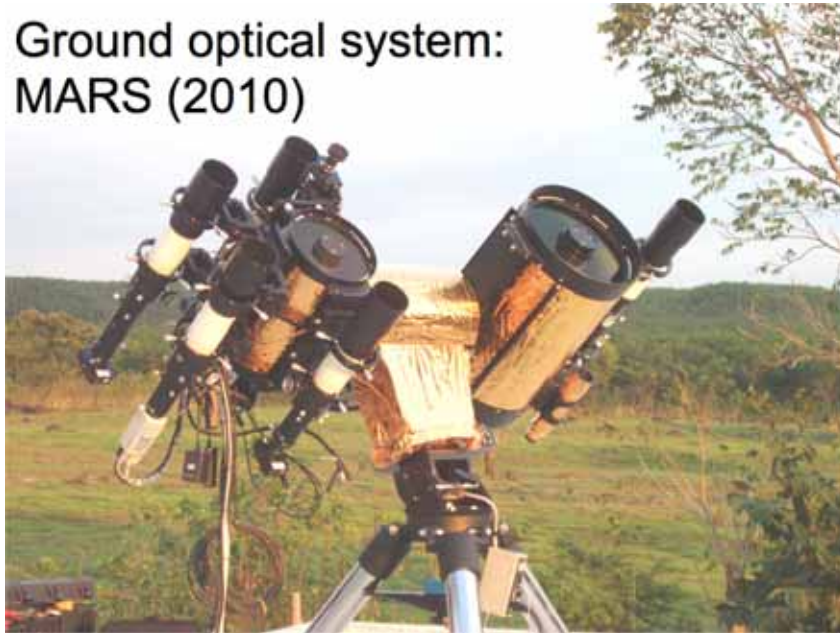


# Primary Assets Used for Imaging Shuttle

Airborne optical system:  
Cast Glance (2011)



Ground optical system:  
MARS (2010)



Ground optical system  
MARS (2012)

