# An Overview of the Design and Development of the GOES R-Series Space Segment

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*GOES-R Launch, 19 November 2016*

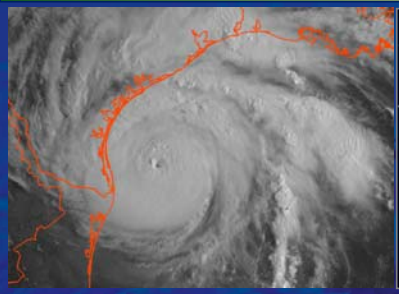
# GOES-R Series Overview

Mission: Provide continuous imagery and atmospheric measurements of Earth's Western Hemisphere and space weather monitoring.

- **GOES-R is the newest generation of United States geostationary weather satellites**
  - **Provides the first update in sensor technology since the GOES-I launch in 1994**
- **Four satellites in the series: GOES-R, S, T and U**
- **Joint mission between NASA and NOAA**
  - **Continuing the successful partnership on weather satellite programs since the 1970s**

| GOES-R Mission Key Requirements |
|---|
| Earth observation from 68ºN to 68ºS lattitude & 150ºE to 2ºW longitude |
| Full Earth disk image every 15 minutes |
| Key Performance Parameter (KPP): Cloud and Moisture Imagery |
| Data Latency less than or equal to product refresh rate |
| 34 atmospheric, land, ocean, space, and solar weather products |
| Replacement for failed spacecraft with on-orbit spare: 3 weeks |
| Mission availability for East and West stations: 0.80 |
| Data outages <=6 hours per year |
| 7 day satellite autonomy |

**Earth Weather**



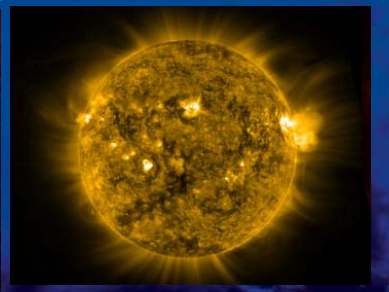
***Advanced Baseline Imager***

***Geostationary Lightning Mapper***

**Space Weather**

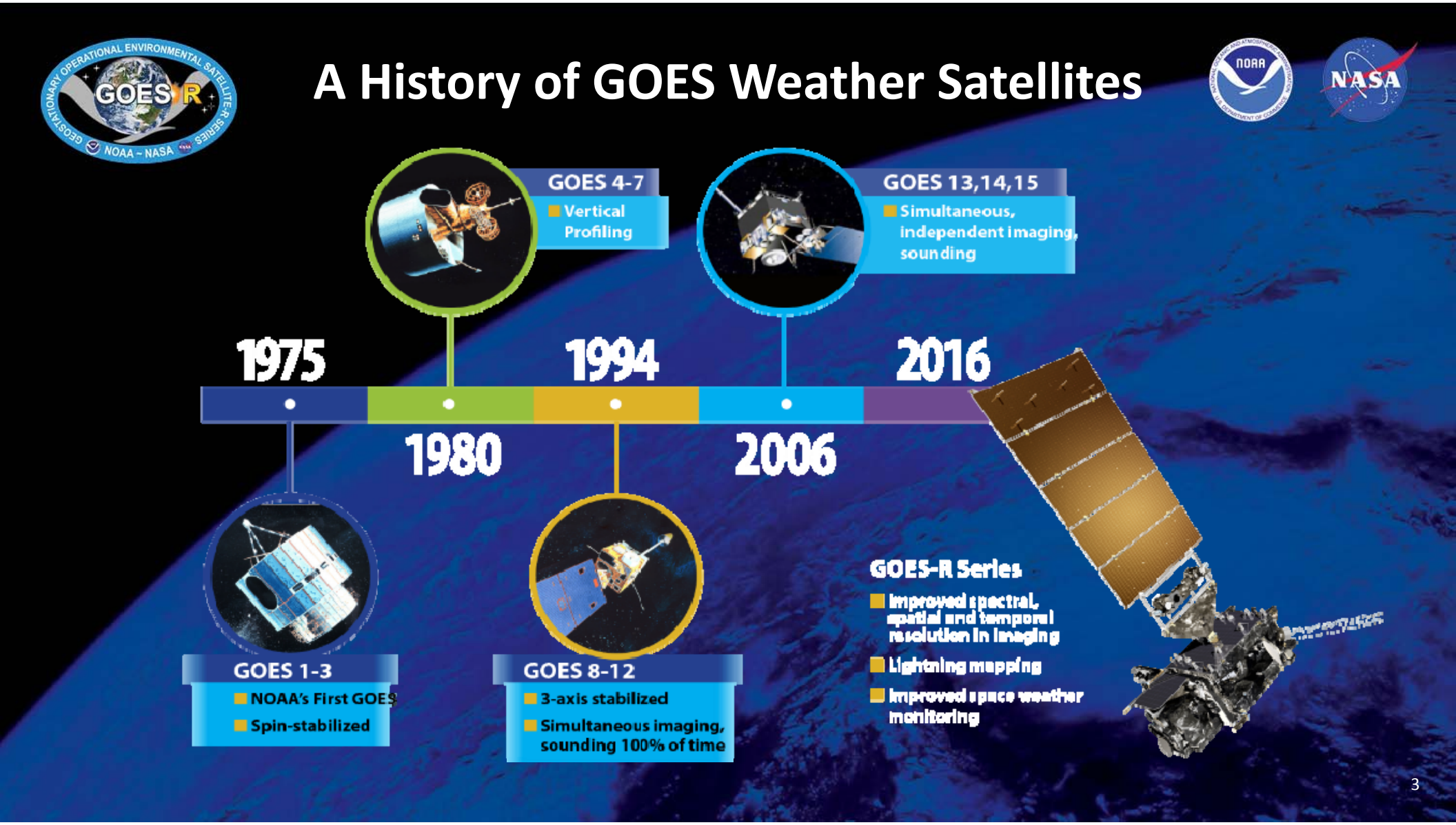
***Space Environment In-Situ Suite & Magnetometer***

**Solar Weather**

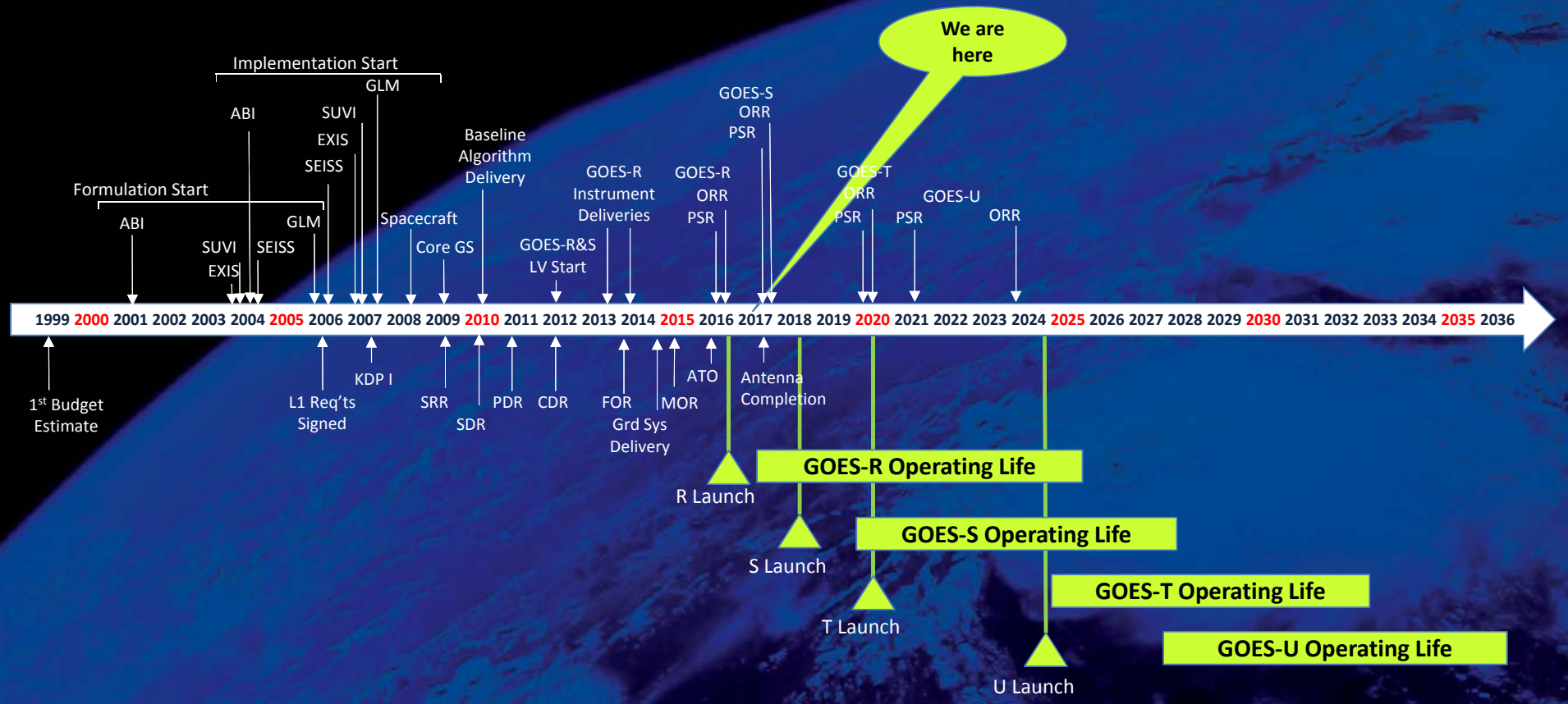


***Solar Ultraviolet Imager & Extreme UV & X-ray Irradiance Sensors***

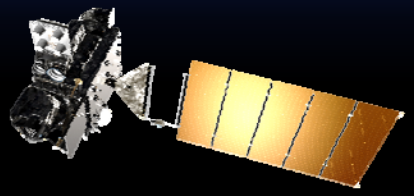
# A History of GOES Weather Satellites



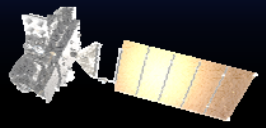
# GOES-R Program Timeline



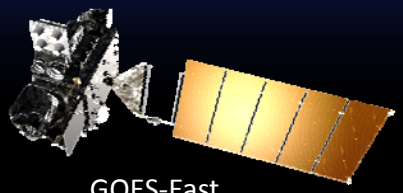
# GOES-R Architecture Overview



GOES-West
137°W

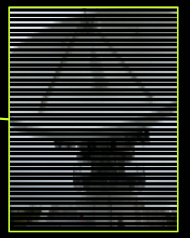


On-orbit Storage
105°W



GOES-East
75°W

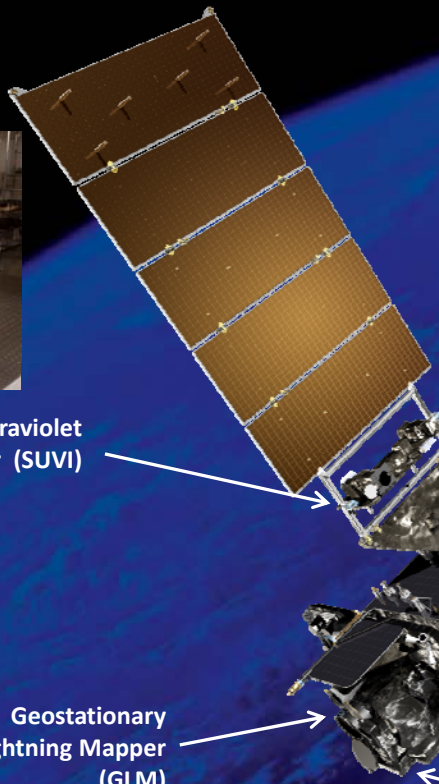
NOAA Satellite Operations Facility, Suitland MD



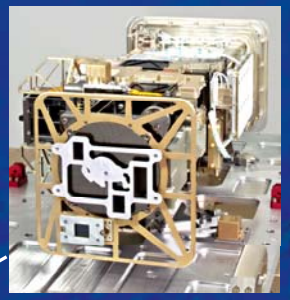
Command and Data Acquisition Station, Wallops VA

Consolidated Backup, Fairmont WV

# GOES-R Space Segment Overview



Extreme Ultraviolet and X-Ray Irradiance Sensor (EXIS)



Space Environment In Situ Suite (SEISS)

Solar Ultraviolet Imager (SUVI)

Magnetometer

Geostationary Lightning Mapper (GLM)

Advanced Baseline Imager (ABI)

# Advanced Baseline Imager (ABI)

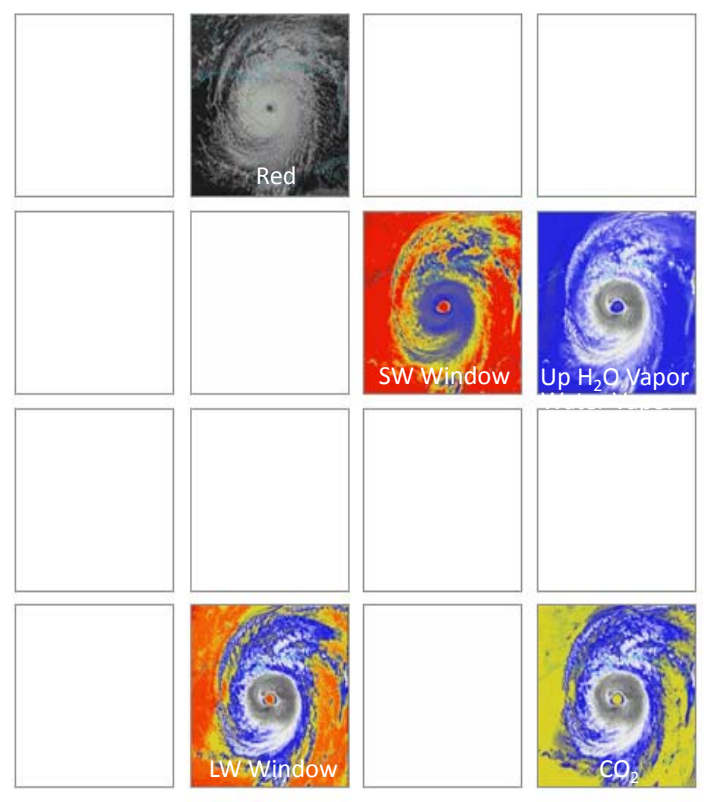
- Primary instrument in GOES-R series
- 16 channel imager
- Measures radiances in the visible and near-infrared wavelengths
- Improves upon current capabilities in spectral (3X), spatial (4X), and temporal resolution (5X)

| | Band | Central Wavelength | SNR or NEdT | Pixel Size (at nadir) | Band Name/Use |
|---|---|---|---|---|---|
| Visible/ Near Infrared | 1 | 0.47 | 300:1 | 1km | Blue |
| | 2 | 0.64 | 300:1 | 0.5km | Red |
| | 3 | 0.86 | 300:1 | 1km | Vegetation |
| | 4 | 1.38 | 300:1 | 2km | Cirrus |
| | 5 | 1.6 | 300:1 | 1km | Snow/Ice |
| | 6 | 2.2 | 300:1 | 2km | Cloud Particle Size |
| Mid-Wave Infrared | 7 | 3.9 | 0.1K | 2km | Shortwave Window |
| | 8 | 6.2 | 0.1K | 2km | Upper-Level Tropospheric Water Vapor |
| | 9 | 6.9 | 0.1K | 2km | Mid-Level Tropospheric Water Vapor |
| | 10 | 7.3 | 0.1K | 2km | Lower-level Water Vapor |
| | 11 | 8.4 | 0.1K | 2km | Cloud-Top Phase |
| Long-Wave Infrared | 12 | 9.6 | 0.1K | 2km | Ozone |
| | 13 | 10.3 | 0.1K | 2km | Clean IR Longwave Window |
| | 14 | 11.2 | 0.1K | 2km | IR Longwave Window |
| | 15 | 12.3 | 0.1K | 2km | Dirty Longwave Window |
| | 16 | 13.3 | 0.3K | 2km | CO2 longwave infrared |

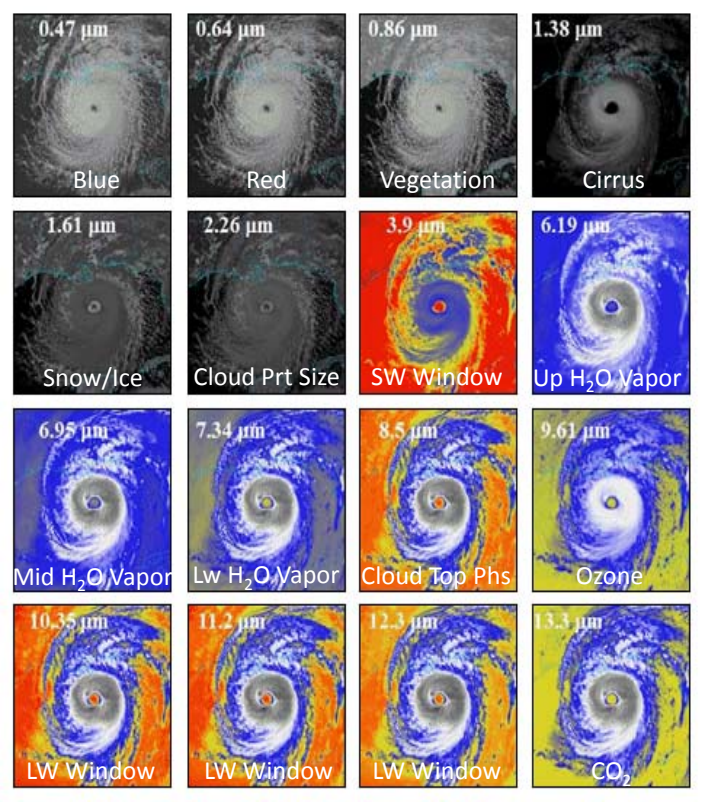
**ABI at Harris Corp**

# GOES-R ABI Provides 3X More Spectral Information

GOES-N Series Imager

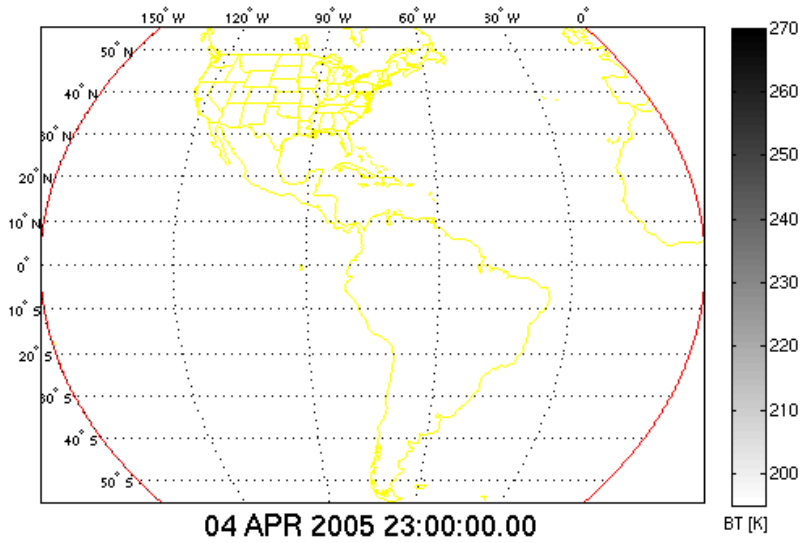


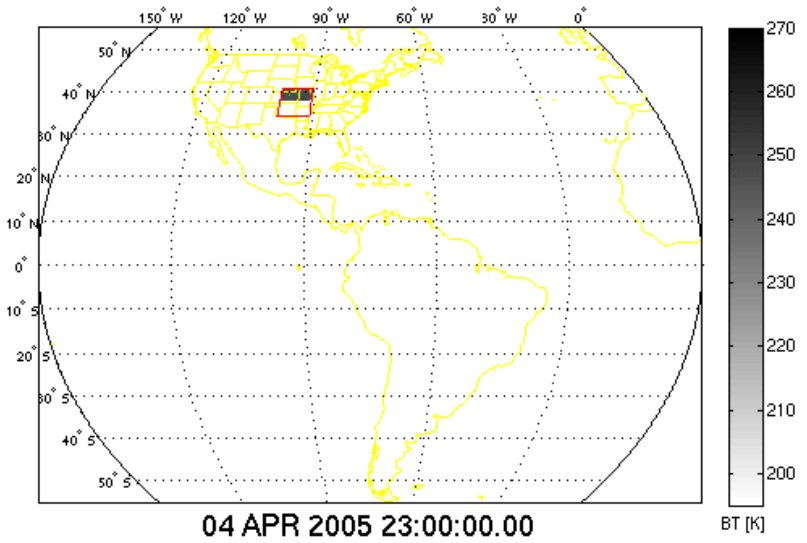

GOES-R Series ABI




Courtesy: NOAA/NESDIS STAR, CIMSS and GOES-R Imagery Team

# GOES-N vs GOES-R Temporal Coverage




In 15 Minutes, GOES-N Imager can scan:

- Most (3/5) of a Full Disk Image

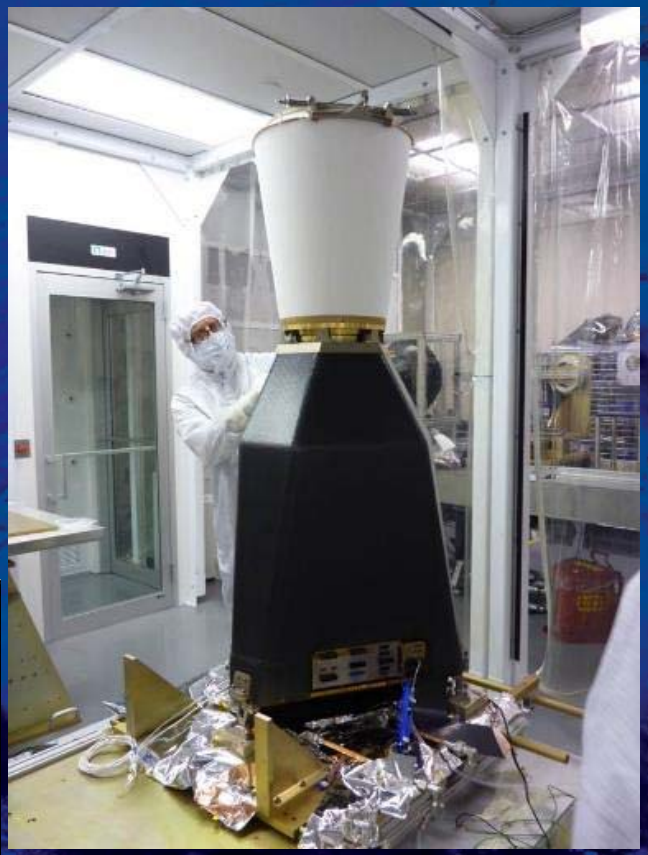
In 15 Minutes, GOES-R ABI can scan:

- 15 Mesoscale Images
- 3 CONUS Images
- 1 Full Disk Image

Courtesy Jun Li and Chian-Yi Liu (CIMSS). Water vapor Image. Data from AWG Proxy Teams.

# Geostationary Lightning Mapper (GLM)

- GLM is a high speed CCD camera that detects ozone emissions at 777.4nm
- Detects total lightning activity across the Western Hemisphere: in cloud, cloud-to-cloud, and cloud-to-ground
  - — Provides coverage over oceans and land
  - – Complements today's land based systems that only measures cloud to ground (~15% of the total lightning)
- – Improves forecaster situational awareness and confidence resulting in more accurate storm warnings (improved lead time, reduced false alarms) to save lives and property

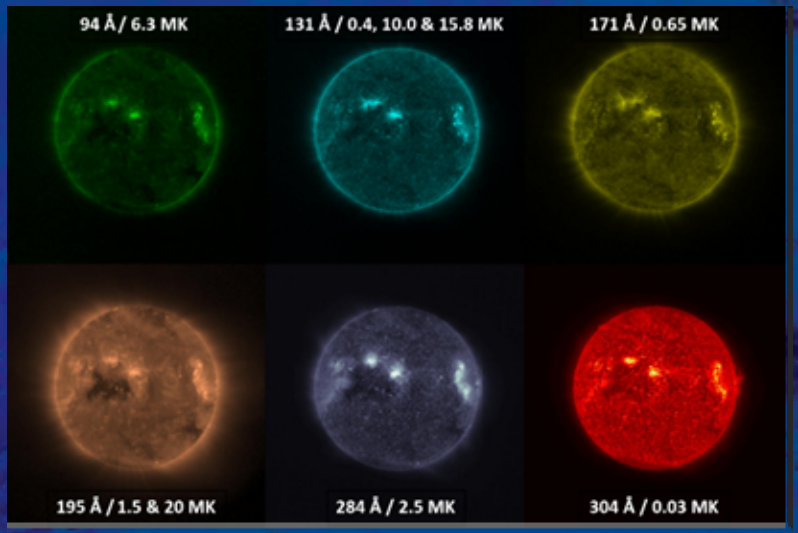


GLM at Lockheed Martin ATC

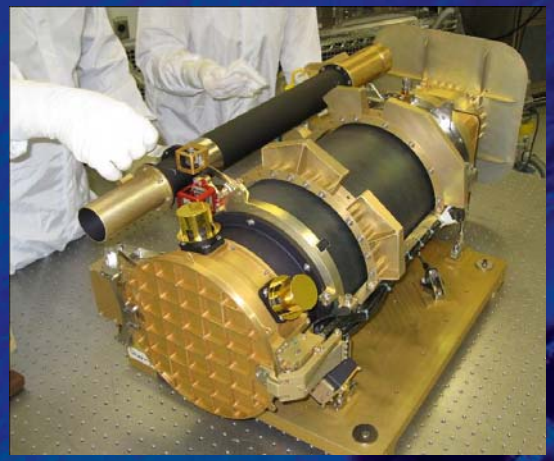
# Solar Ultraviolet Imager (SUVI)

- Continuously images the sun in 6 extreme ultraviolet wavelengths to characterize active region complexity
- Locates coronal holes, flares and coronal mass ejection source regions
- Thematic maps will be used to automate the identification and location of bright regions, flares and coronal hole boundaries in solar images
- Improves geomagnetic storm forecasting

**1st SUVI Data Release**







**SUVI at Lockheed Martin ATC**

Thematic



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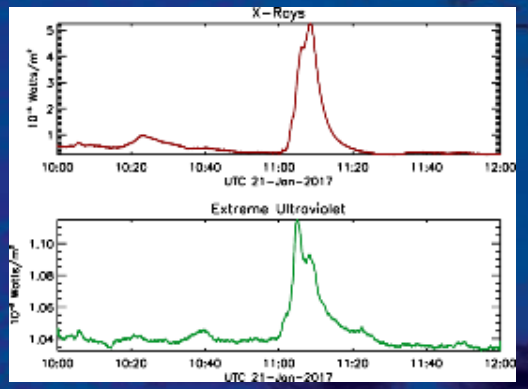
# Extreme Ultraviolet and X-ray Irradiance Sensors (EXIS)

- EXIS has two sensors to measure solar radiation:
  - Extreme Ultraviolet Sensor (EUVS): monitors solar variations that affect satellite drag, and ionospheric changes impacting communication and navigation operations
  - X-Ray Sensor (XRS): detects the beginning, duration, and magnitude of solar X-ray flares
- Provides improved solar flare warnings for communications and navigation disruption
- Provides input to models predicting impacts on satellites, astronauts, and airline passengers on polar routes, and power grid performance

**EXIS Observes a Solar Flare**



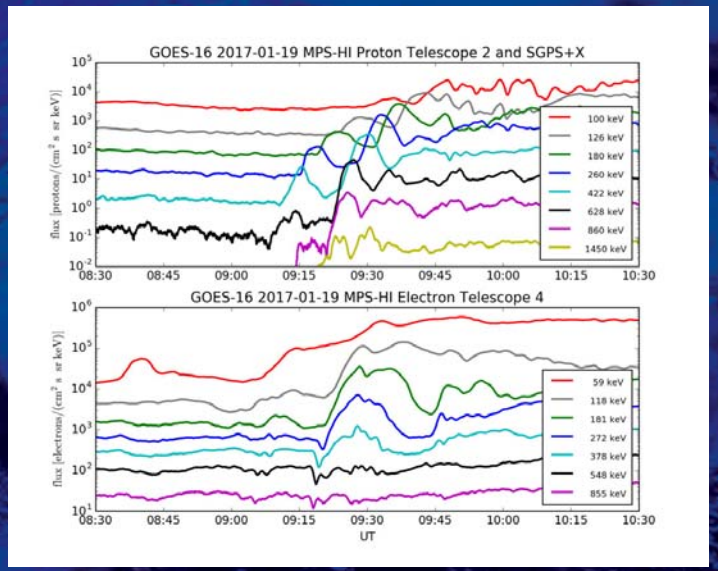

**EXIS at the University of Colorado LASP**

# Space Environment in-Situ Sensor Suite (SEISS)

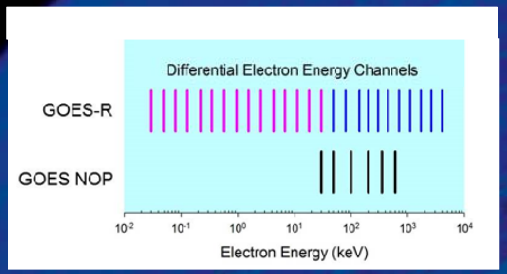
- SEISS consists of energetic particle sensors to monitor proton, electron and alpha particle fluxes
- SEISS provides:
  - More accurate monitoring of energetic particles responsible for radiation hazards to humans and spacecraft
  - Better monitoring of ionizing responsible for spacecraft charging
  - Improved warning of high flux events, mitigating damage to radio communication

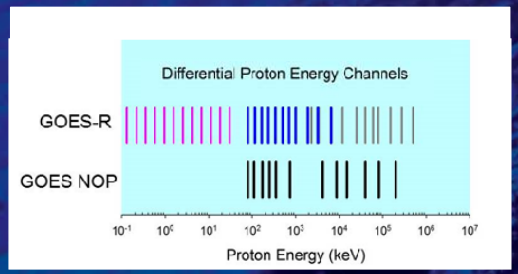
**SEISS at Assurance Technology Corp**

**1st SEISS Data Release**




**SEISS Monitors more Electron and Proton Energy Levels than GOES-N**



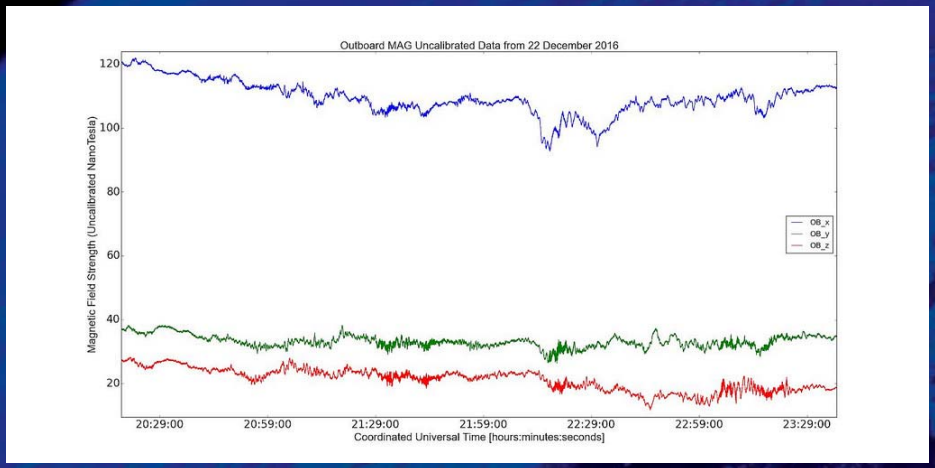
# Magnetometer

- Consists of two sensors located on an 8 meter deployable boom structure that distances them from the magnetic signature of the spacecraft
  - Each sensor uses 3 flux gate magnetometers to measure the orthogonal vector components of the Earth's mag field
- Magnetic field measurements provide information on the general level of geomagnetic activity, and enable detection of sudden storm commencements, substorms, & magnetopause crossings

**Magnetometer Sensor at MEDA**

**Mag Boom at ATK**

**1st Mag Data Release**



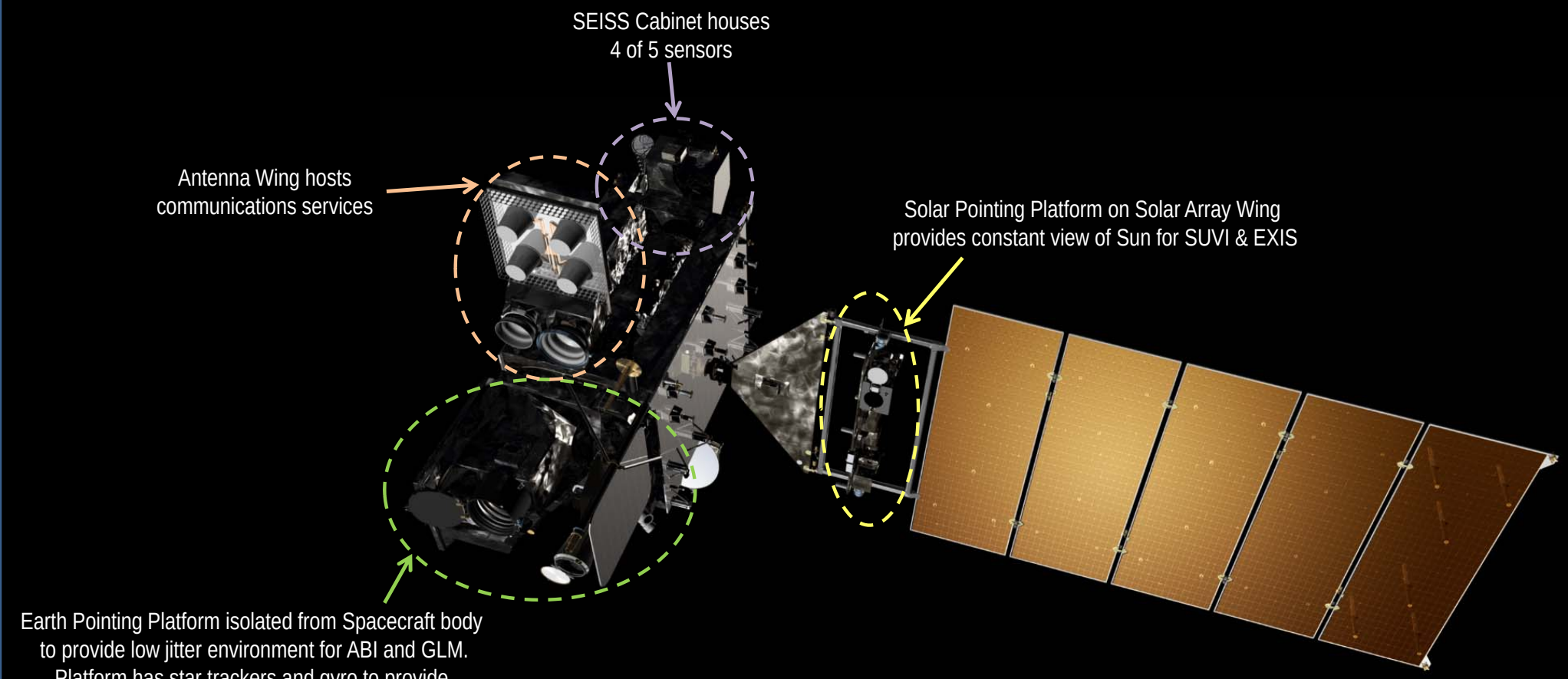
# GOES-R Communications Services

- **Search and Rescue Satellite Aided Tracking (SARSAT)**
  - All GOES-R satellites support the SARSAT system by relaying distress signals from 406 MHz emergency beacons
- **Information Network (HRIT/EMWIN)**
  - Delivers selected imagery, charts, other environmental data products, and text messages (NWS Watches and Warnings) to hemispheric users.
  - Combination of today's LRIT (Low Rate Information Transmission) and Emergency Managers Weather Information Network services
- **Data Collection System (DCS)**
  - GOES-R spacecraft relay data transmissions for ~20,000 in-situ environmental data platforms from across the hemisphere
- **GOES Rebroadcast (GRB)**
  - GRB will contain the Level 1b data from each of the GOES-R Series instruments and is the GOES-R Series version of today's GOES Variable format (GVAR)

Emergency Beacons

Remote Automated Weather Stations transmitting to GOES

# GOES-R Spacecraft Overview



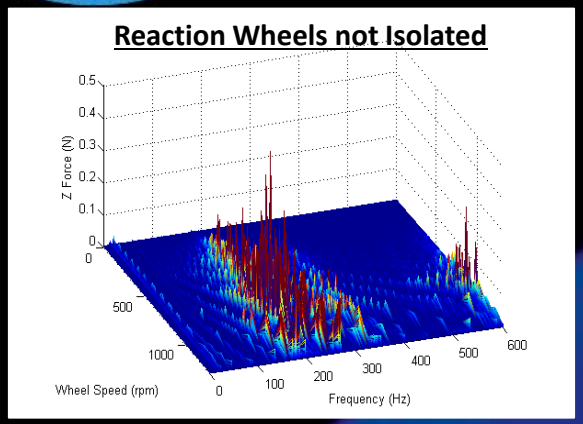

*Magnetometer & 5th SEISS sensor on +X panel not shown*

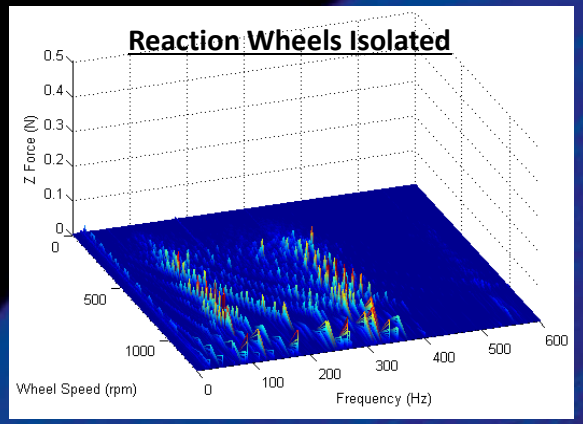
# GOES-R Spacecraft Design

- Customized Lockheed Martin A2100 spacecraft with upgrades to meet GOES-R requirements
  - Stable and accurate pointing achieved with:
    - Isolated Earth Pointing Platform
    - Isolated Reaction Wheels
    - Correction of spacecraft-induced torques with reaction wheel speed changes
    - Accurate attitude sensing with gyro, star tracker, and diagnostic accelerometers
  - No observing time lost to station keeping or momentum adjustment manuevers
    - Low thrust rocket engines with correction of applied torques
  - Onboard orbit determination
    - 1st civilian use of GPS in geo orbit
  - High speed, error free data transmission
    - SpaceWire data bus
    - GOES-R Reliable Data Delivery Protocol
  - EMI compatibility with UHF payloads
    - Stringent EMI design and test methods

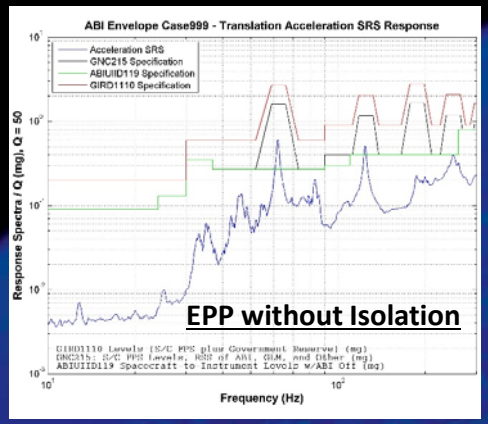
| Key GOES-R Space Segment Performance Parameters | | | |
|---|---|---|---|
| | | Requirement | Performance |
| **Pointing** | Attiude Knowledge - Diurnal | 45µrad 3σ | 26µrad 3σ |
| | Attitude Integrated Rate Error provided to ABI - 1 Sec | 1µrad 3σ X&Y, 1.5µ 3σ Z | 0.8µrad 3σ |
| | Attitude Integrated Rate Error provided to ABI - 30 Sec | 2µrad 3σ X&Y, 2.5µ 3σ Z | <1.0µrad 3σ |
| | Attitude Integrated Rate Error provided to ABI - 300 Sec | 7µrad 3σ per axis | <=1.8µrad 3σ |
| | Attitude Integrated Rate Error provided to ABI - 900 Sec | 18.5µrad 3σ per axis | <=2.7µrad 3σ |
| **Orbit Knowledge** | In-Track Position | 75m 3σ | 13m 3σ |
| | Cross-Track Position | 75m 3σ | 7.3m 3σ |
| | Radial Position | 100m 3σ | 20m 3σ |
| | Velocity | 6 cm/sec 3σ | 0.85 cm/sec 3σ |
| **Navigation Accuracy** | ABI | 28µrad (1km at nadir) 3σ | 20µrad 3σ |
| | GLM | 140µrad (5km at nadir) 3σ | <90µrad 3σ |
| **EMI** | EMI (for SAR and DCPR) in UHF band | -12 dBµV/m | -24 dBµV/m |
| **Raw Data Transmission** | Transmit Data Rate | 120Mbps | 120Mbps |
| | Raw Data Link Margin | 3dB | 9dB |
| **Availability** | Lost observation time | <120 min per year | 0 min per year |
| **Fuel Lifetime** | For on-orbit storage + operations | 15 years | 20 years |

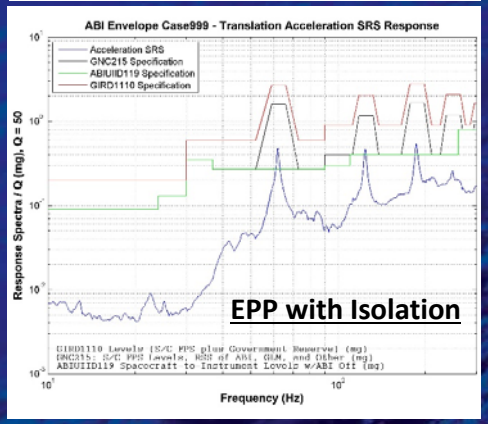
# GOES-R Techniques for Stable Pointing



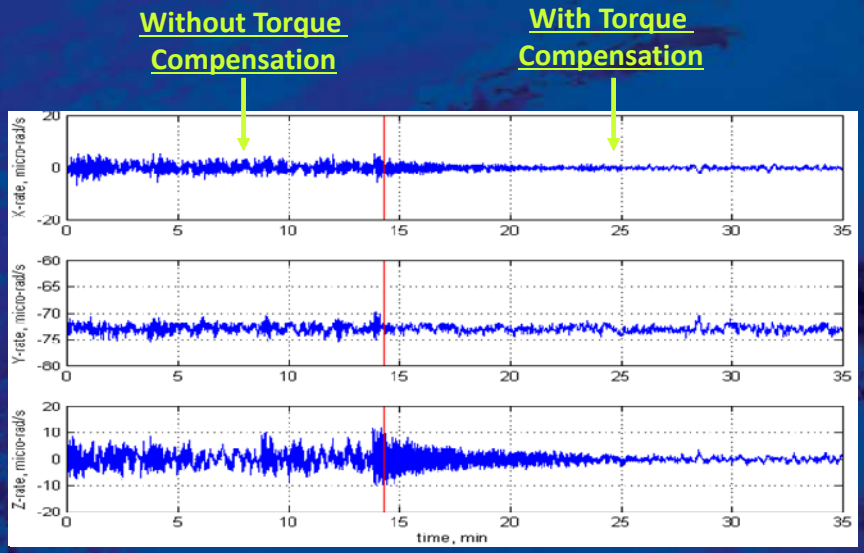




Reaction Wheels Isolation to Minimize Disturbances Transmitted to Spacecraft




Earth Pointing Platform Isolated to Minimize Disturbances to ABI & GLM

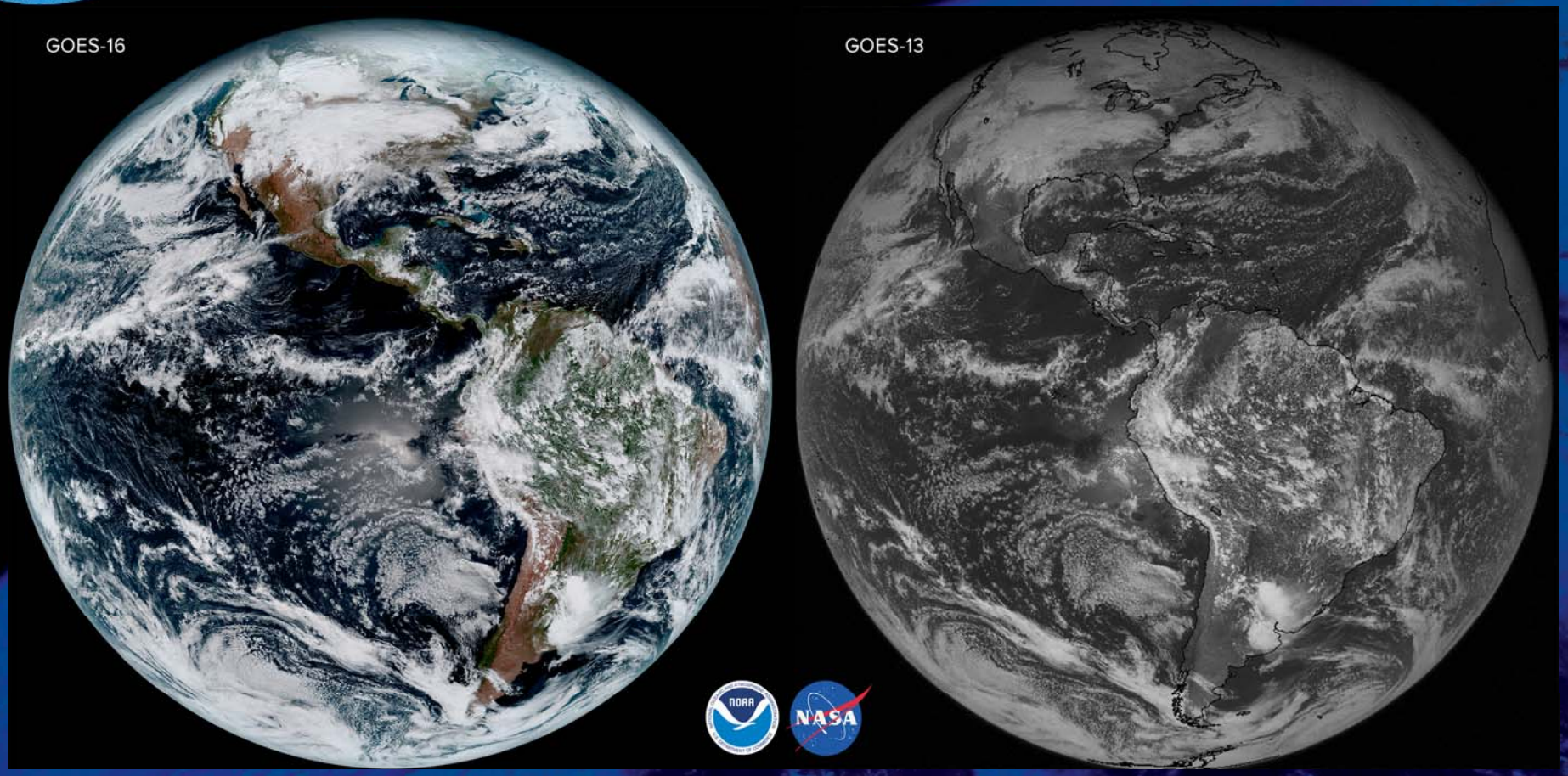



Spacecraft Body Rates during ABI Scanning, before and after Enabling Torque Compensation

# GOES-16 Imagery

**ABI 1st Light, January 7, 2017**
**RGB using 0.47um, 0.64um, 0.86um**

# First ABI Public Release

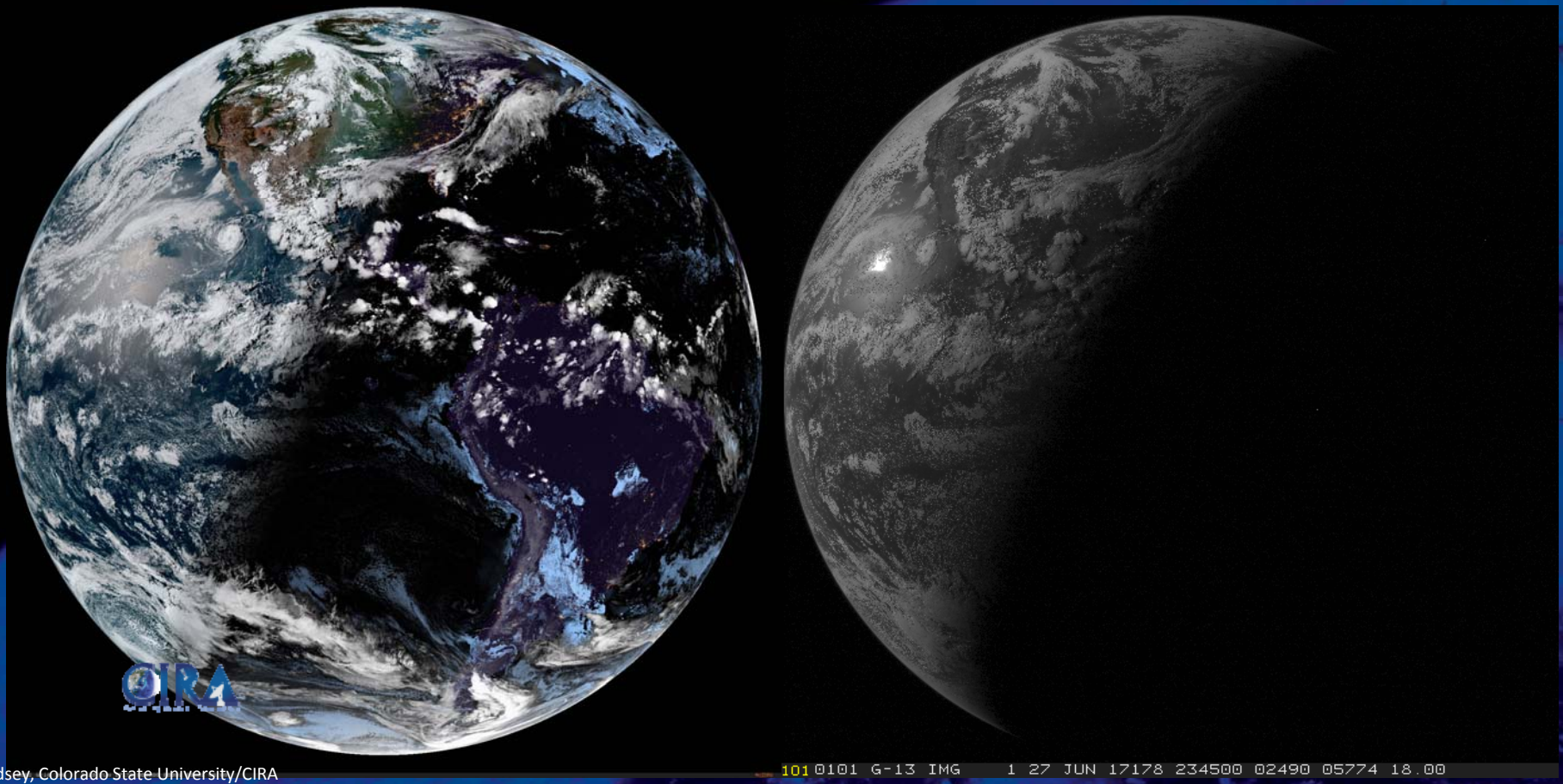



GOES-16 vs GOES-13 on January 15, 2017

# Full Disk Imagery Increased From 8X to 96X per Day

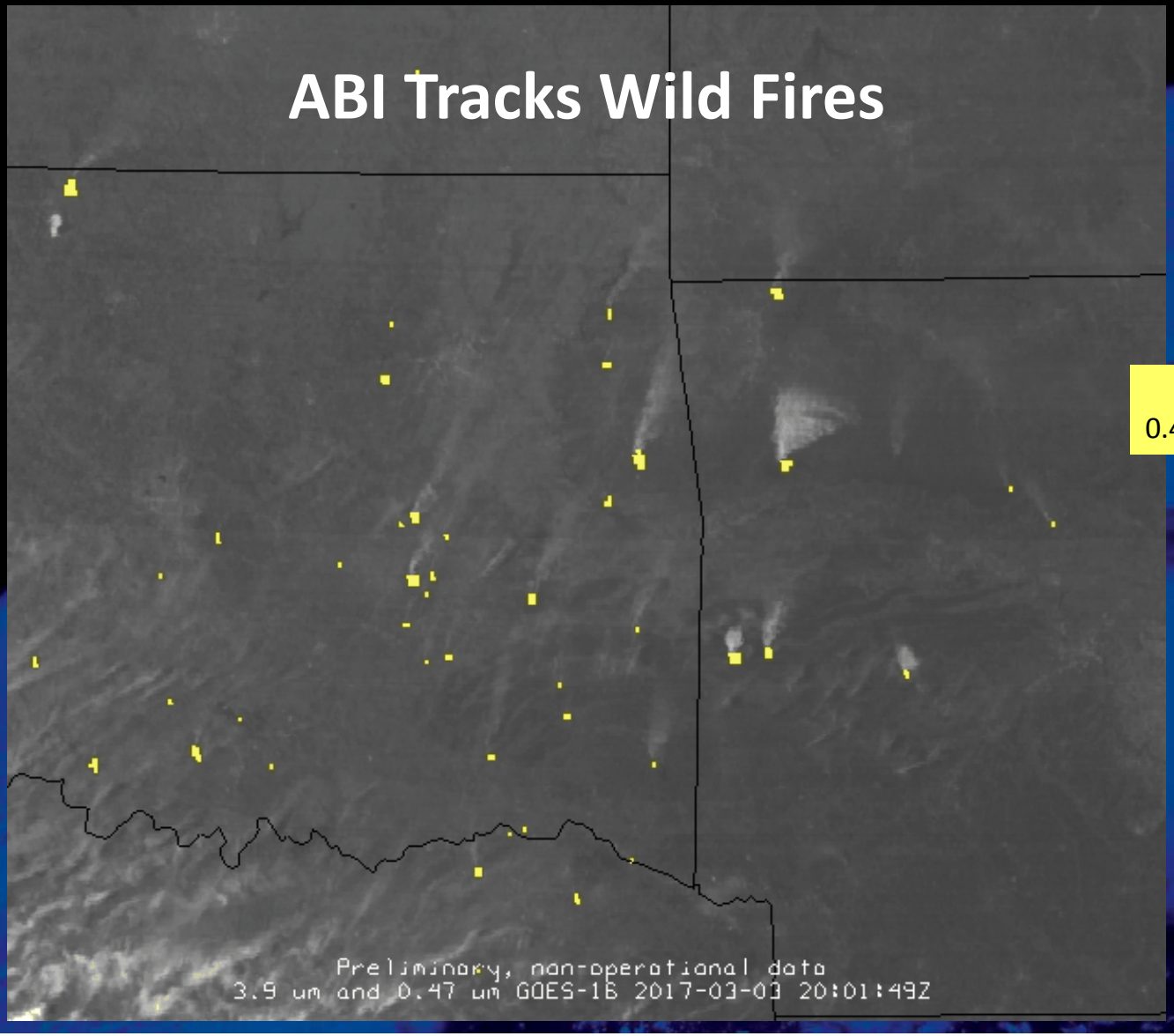
**GOES-R every 15 minutes**

**GOES-N every 3 hours**




Courtesy Dan Lindsey, Colorado State University/CIRA

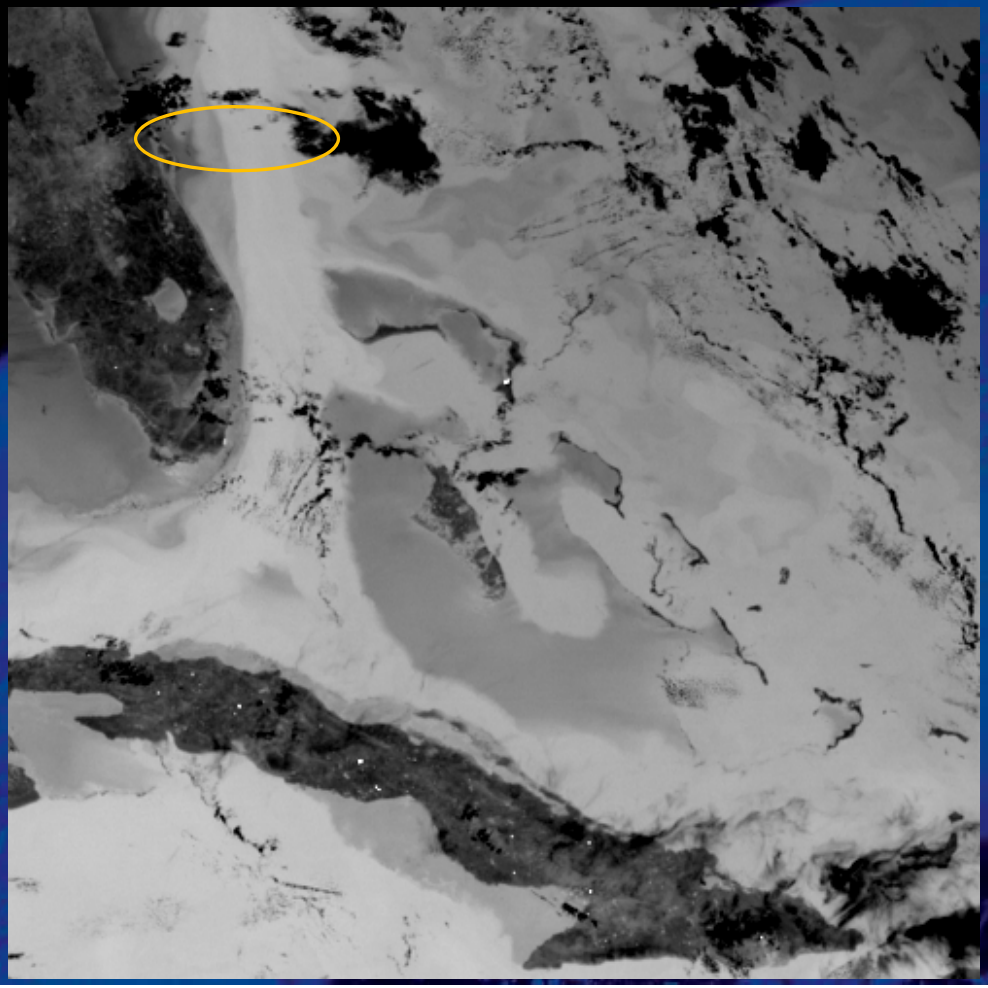
# ABI Tracks Wild Fires



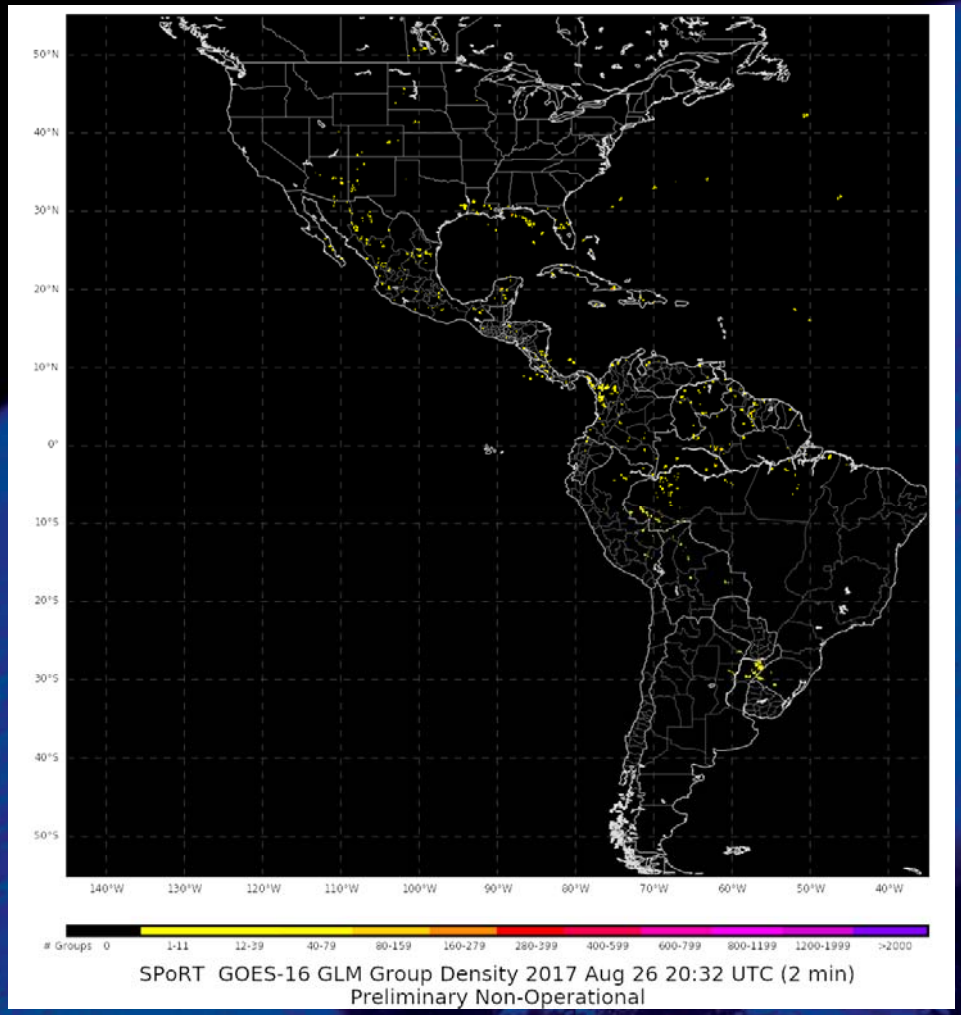

3.9 um (hotspots)
0.47 um (smoke plumes)

*Courtesy Bill Line,*
*National Weather Service*

# ABI 3.9um Channel Sees Atlas V Launch

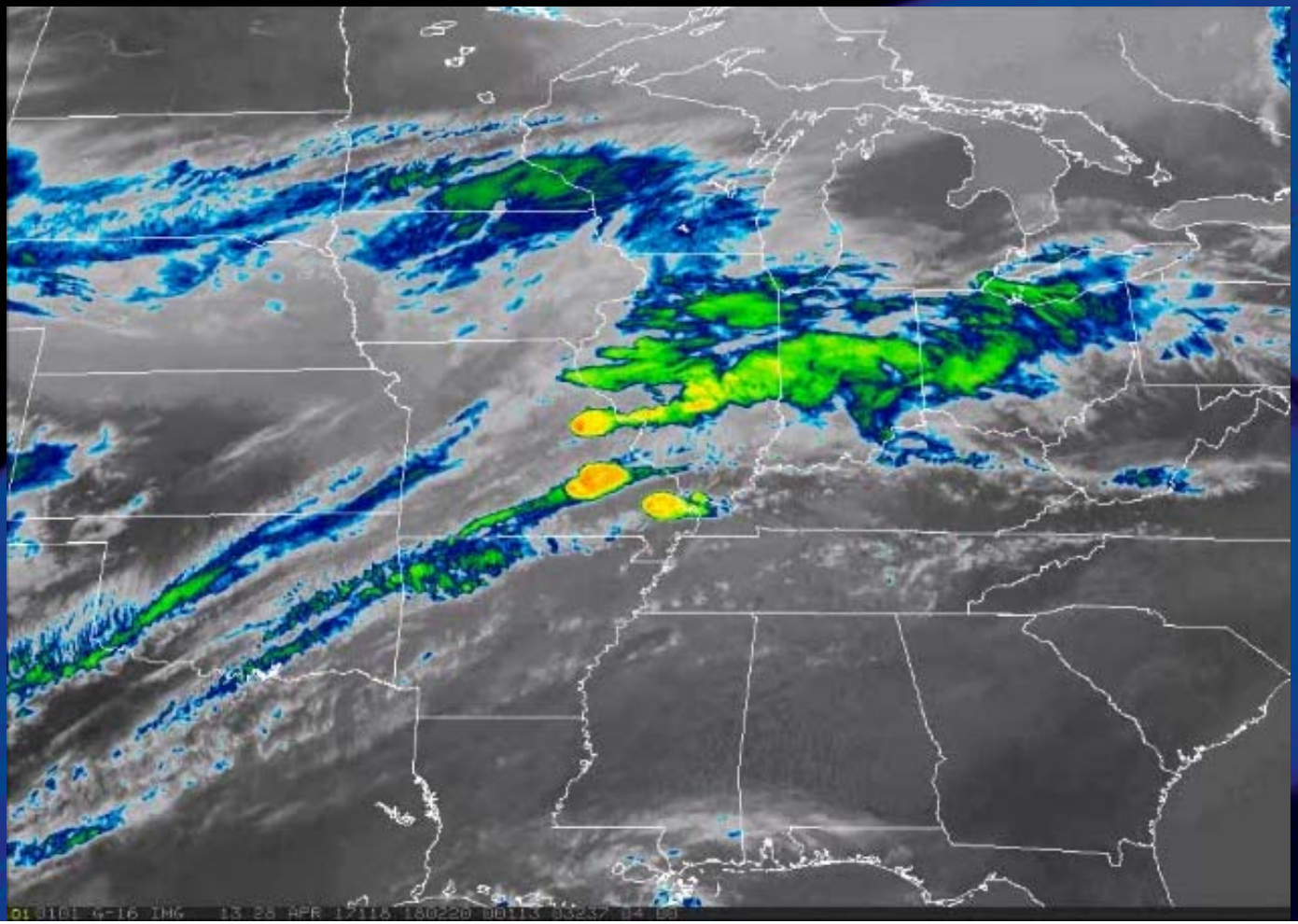


# GLM Lightning Map

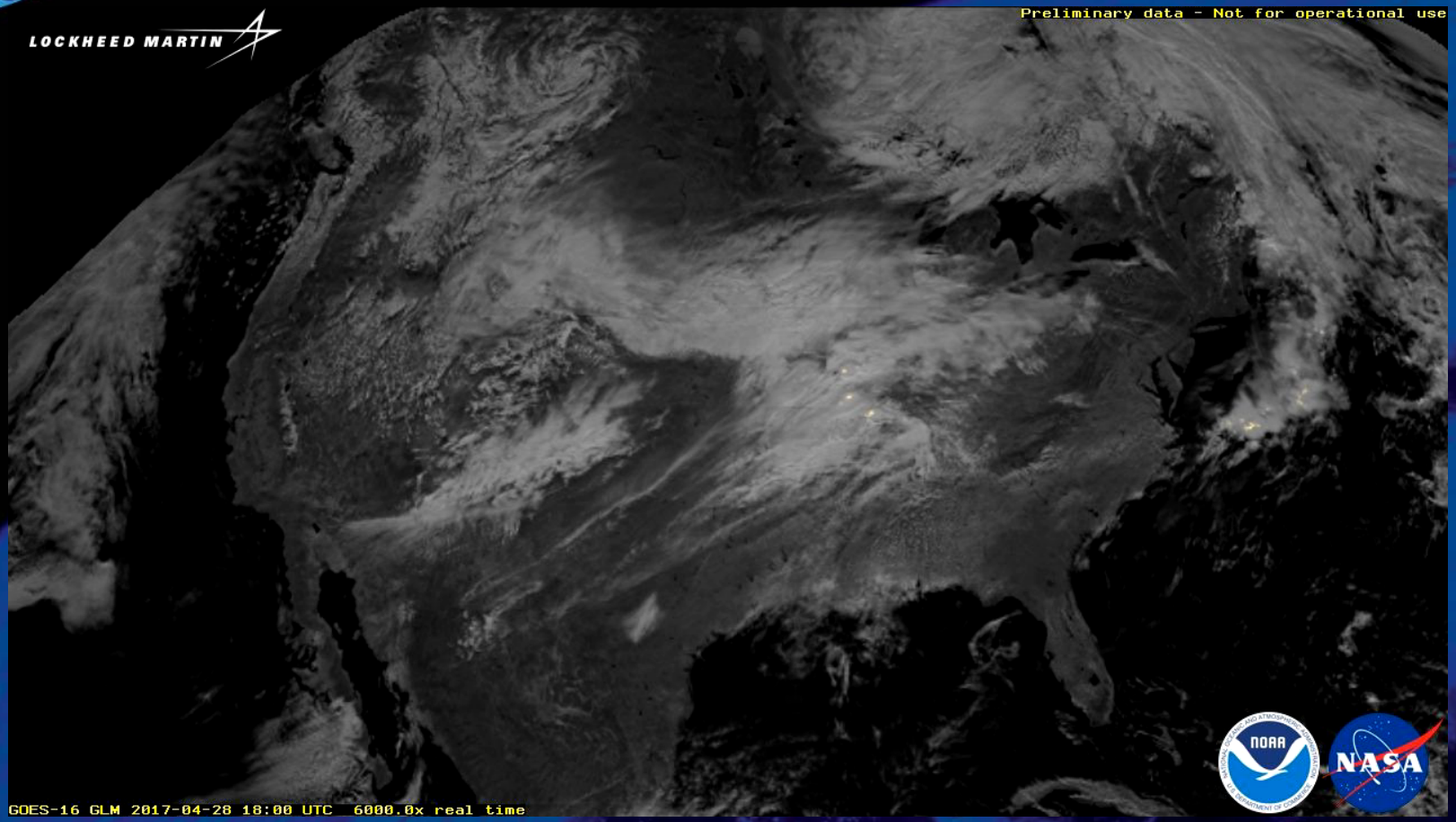



Courtesy NASA Short-term Prediction Research and Transition Center

# ABI Band 13 Infrared Imagery
# Severe Weather in Eastern U.S.



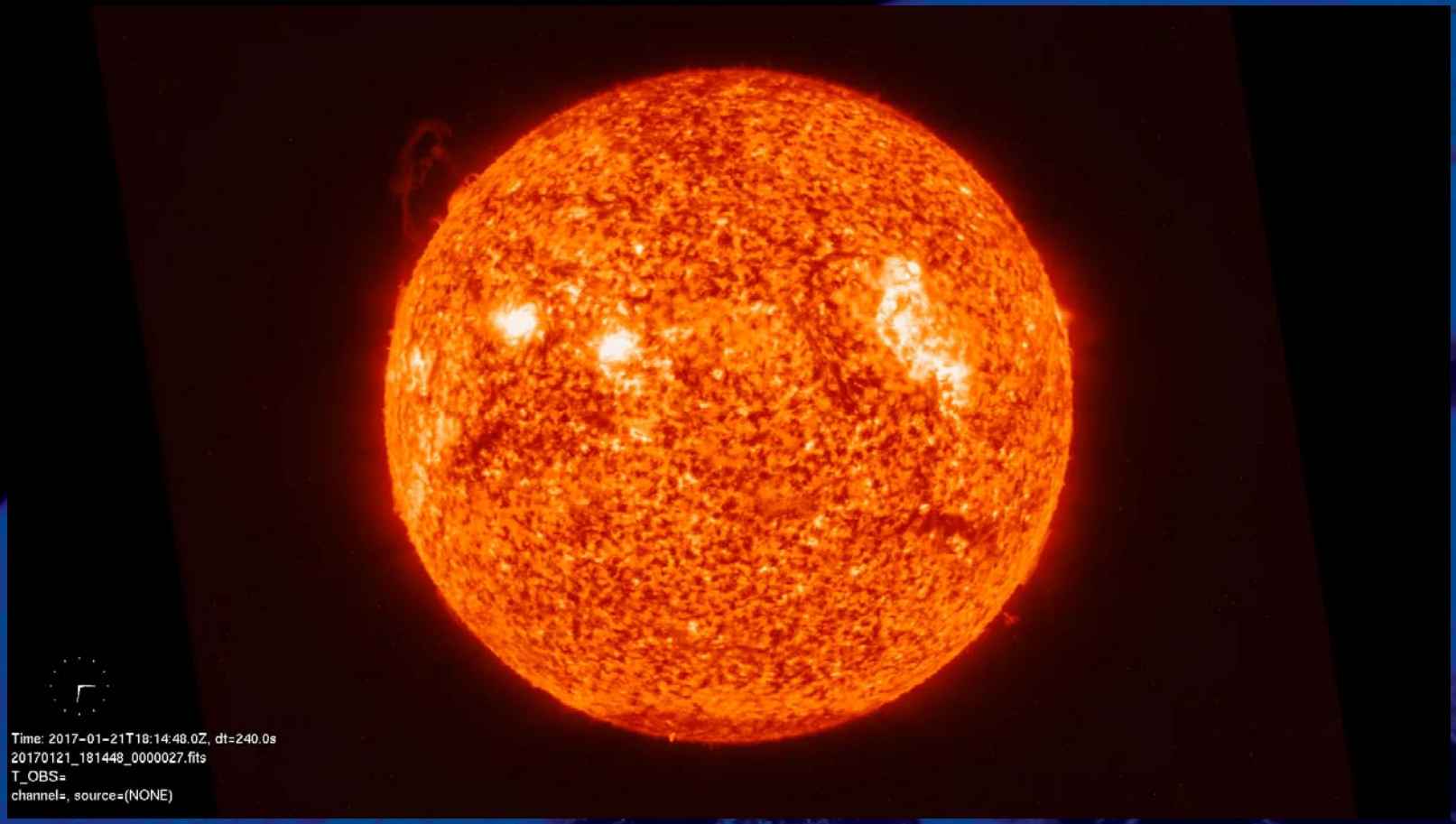
# GLM Lightning Detected during Severe Weather in Eastern U.S.




*Courtesy Lockheed Martin*

GLM lightning superimposed on GLM background

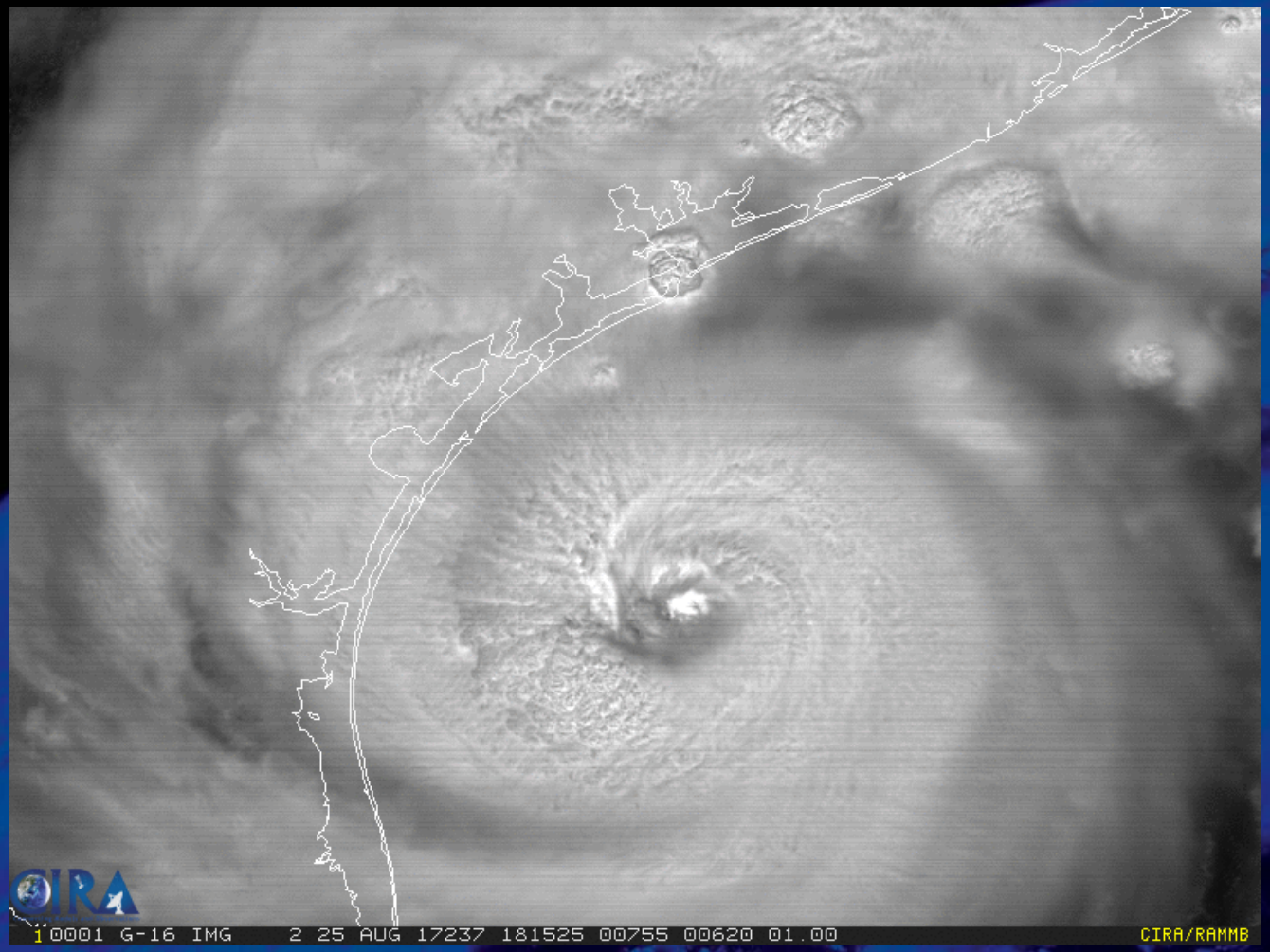
# SUVI 304Å Channel




*Courtesy*
*Lockheed Martin*

# Hurricane Harvey Strikes Texas Coast

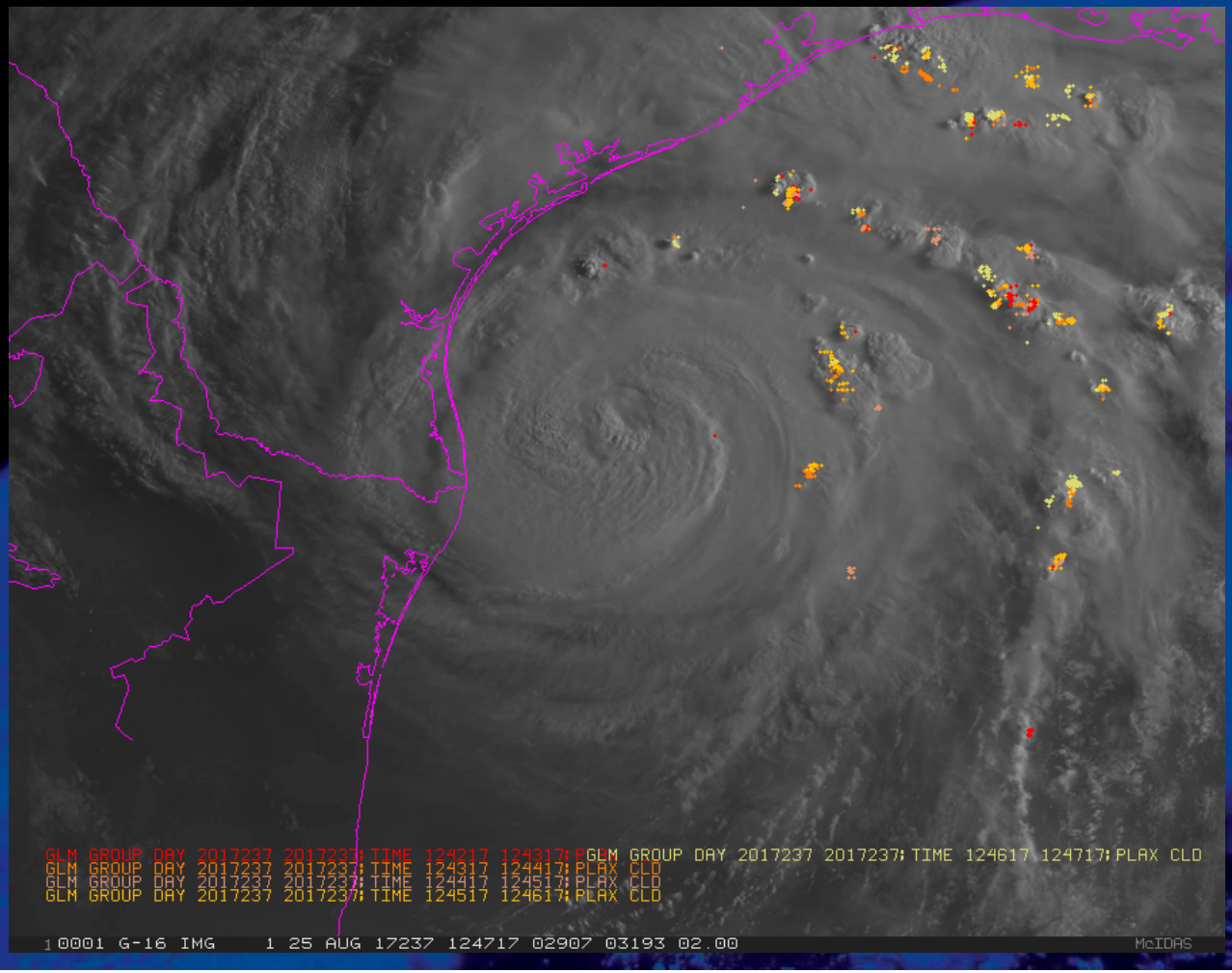
ABI 0.64um




*Courtesy CIRA*

# Lightning in Hurricane Harvey

**ABI 0.47um Imagery with GLM lightning groups**




*Courtesy UW CIMSS*

# GOES-S Getting Ready for Launch

GOES-S Satellite
at Lockheed Martin

# Many thanks to the GOES-R Team!


**Check out the latest GOES-16 Imagery at:**

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**http://cimss.ssec.wisc.edu/goes/blog/**

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