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

Pam Sullivan, NASA/GSFC
Alexander Krimchansky, NASA/GSFC
Tim Walsh, NOAA

October 2017

GOES-R Launch, 19 November 2016

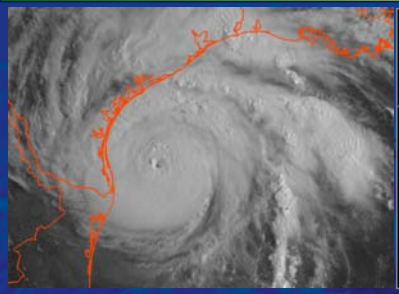
GOES-R Series Overview

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



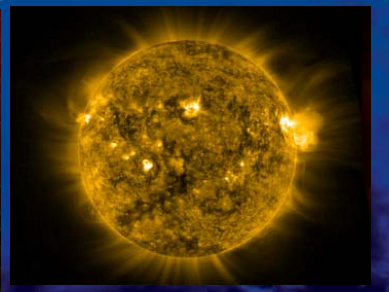
Advanced Baseline Imager

Geostationary Lightning Mapper

Space Weather

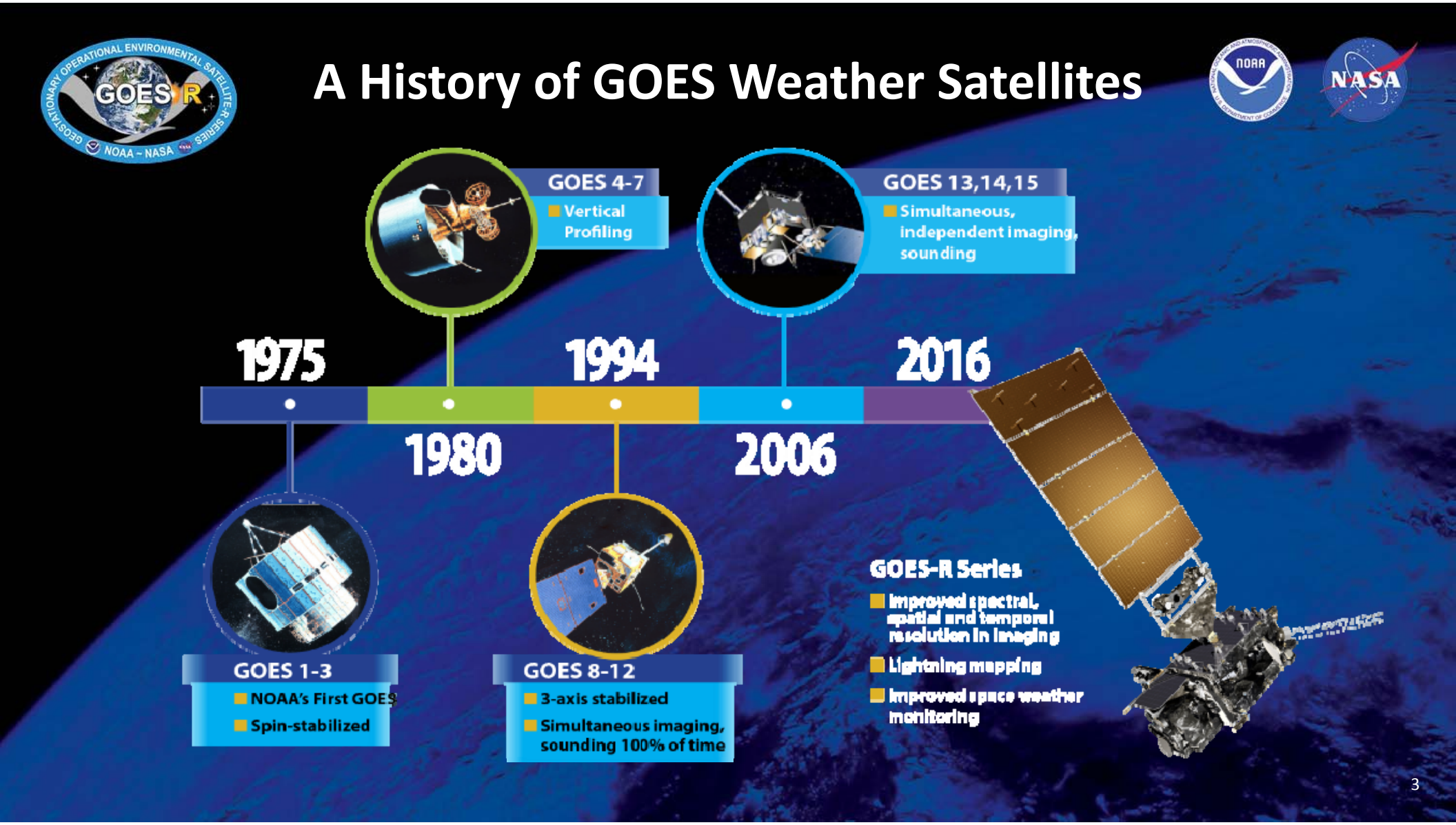
Space Environment In-Situ Suite & Magnetometer

Solar Weather

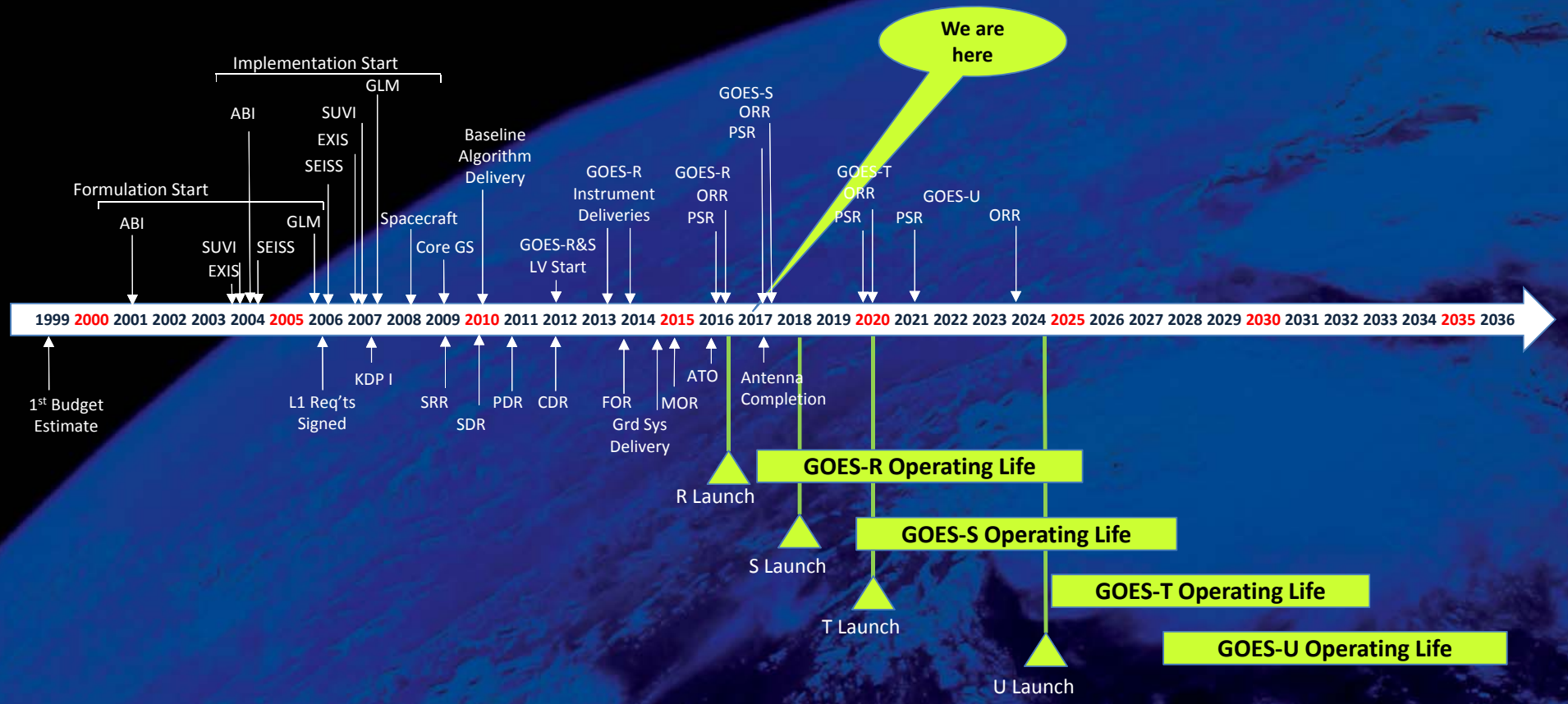


Solar Ultraviolet Imager & Extreme UV & X-ray Irradiance Sensors

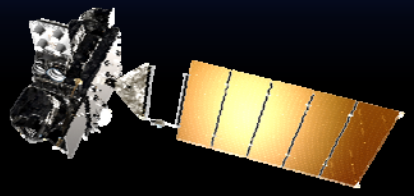
A History of GOES Weather Satellites



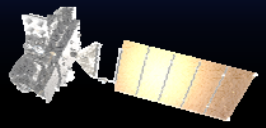
GOES-R Program Timeline



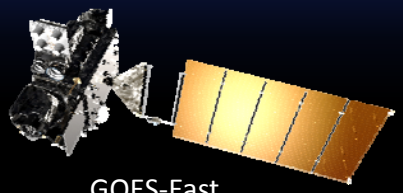
GOES-R Architecture Overview



GOES-West
137°W

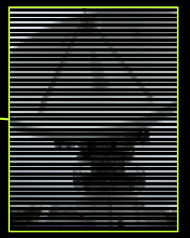


On-orbit Storage
105°W



GOES-East
75°W

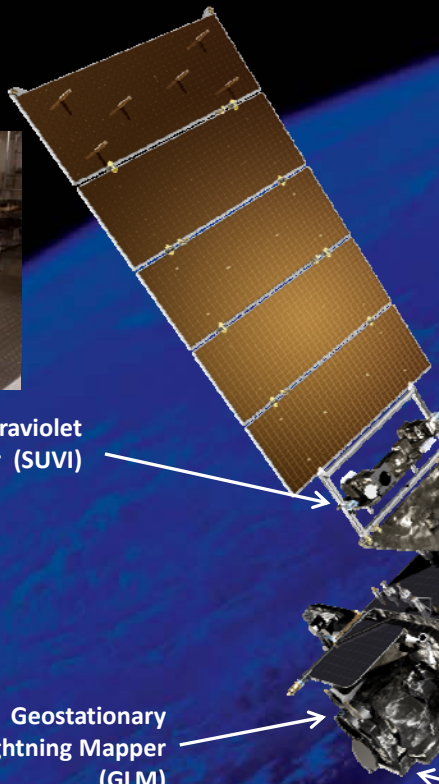
NOAA Satellite Operations Facility, Suitland MD



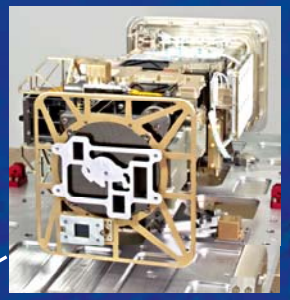
Command and Data Acquisition Station, Wallops VA

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)

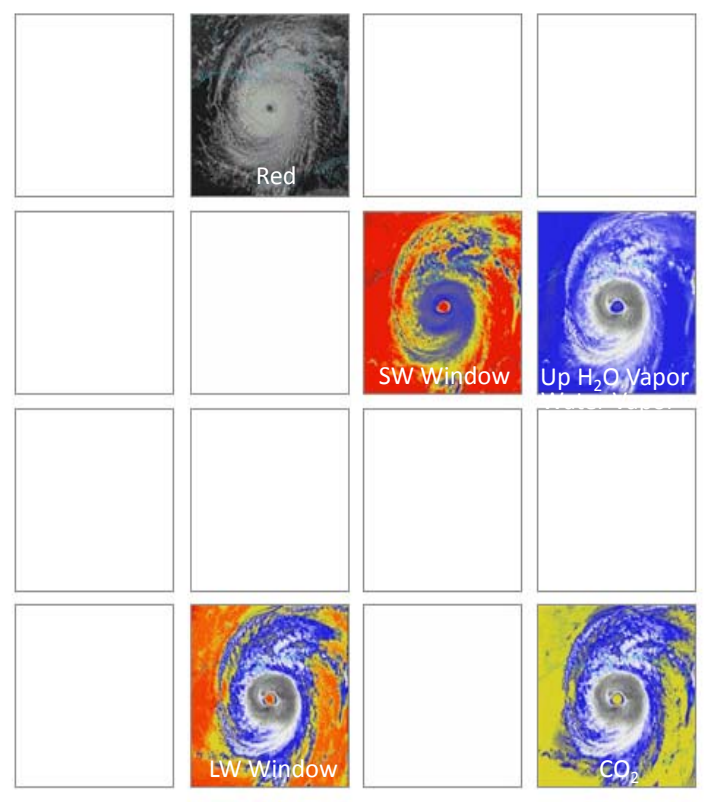
- Primary instrument in GOES-R series
- 16 channel imager
- Measures radiances in the visible and near-infrared wavelengths
- Improves upon current capabilities in spectral (3X), spatial (4X), and temporal resolution (5X)

	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

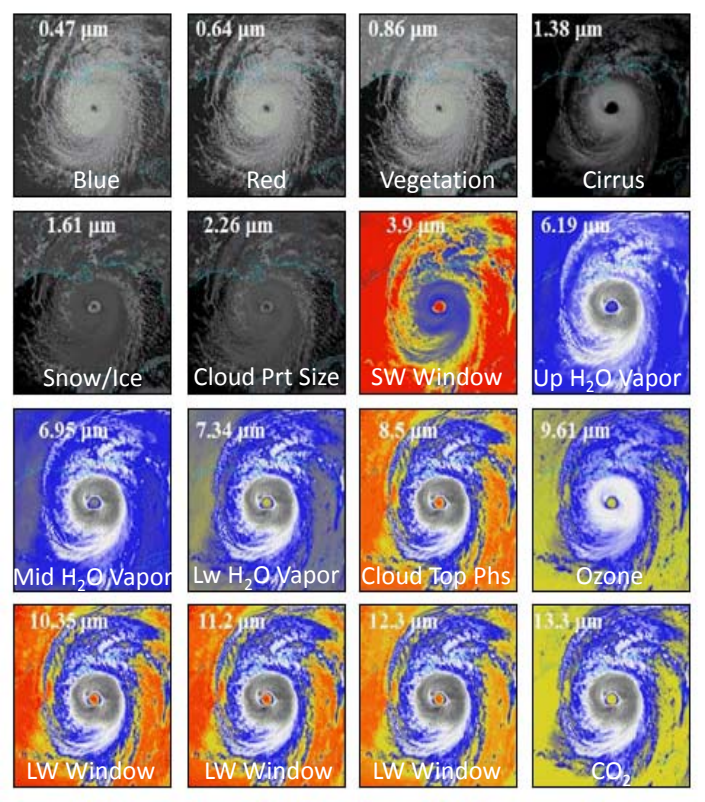
ABI at Harris Corp

GOES-R ABI Provides 3X More Spectral Information

GOES-N Series Imager

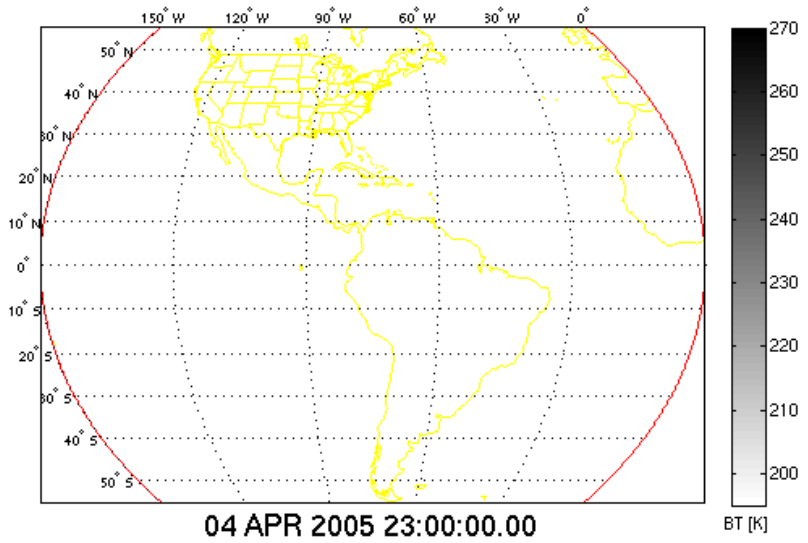


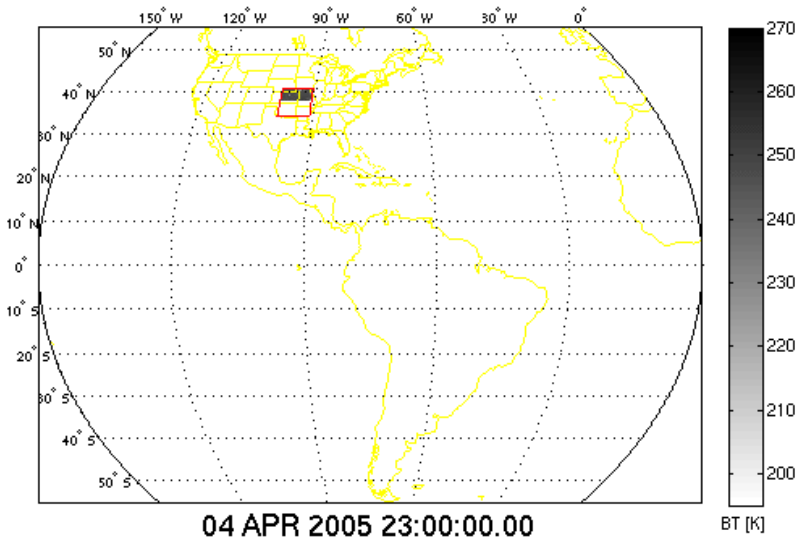
GOES-R Series ABI



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

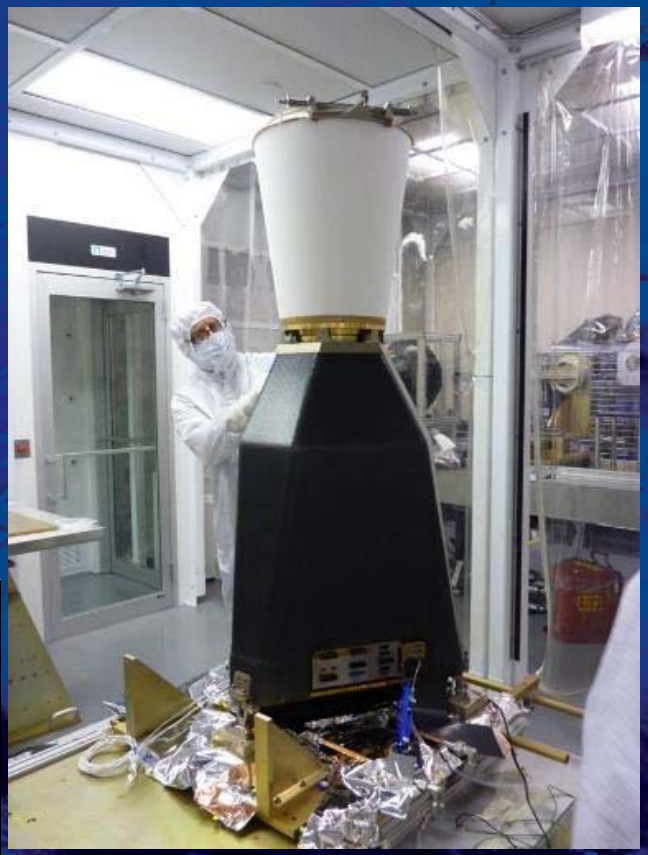
In 15 Minutes, GOES-R ABI can scan:

- 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

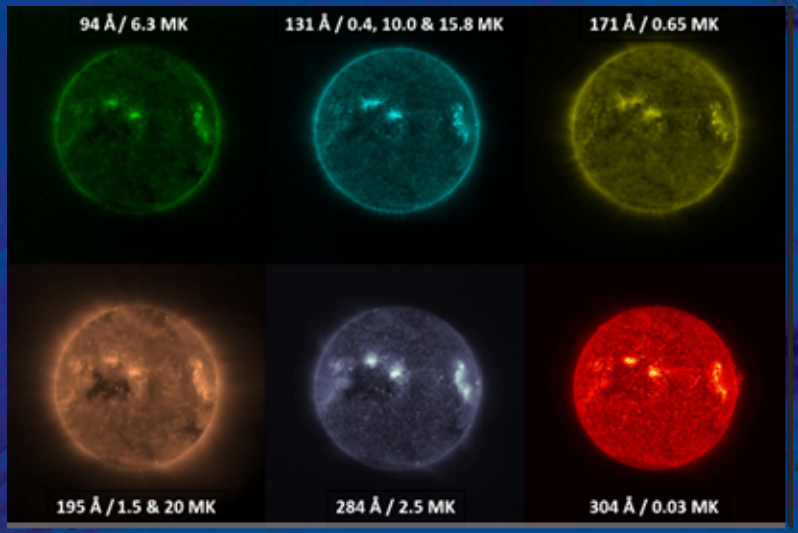


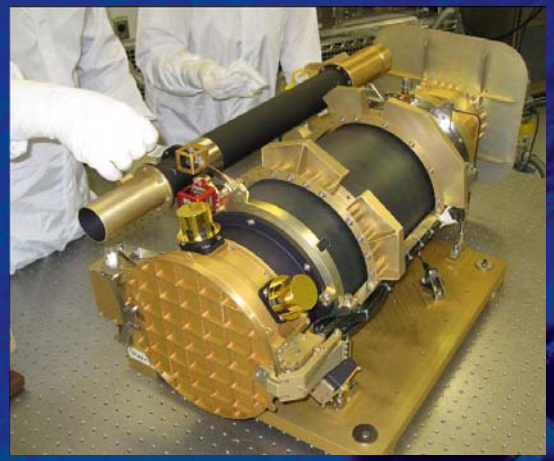
GLM at Lockheed Martin ATC

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

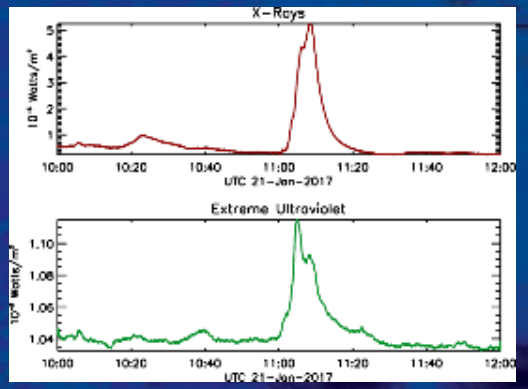
Thematic

11

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



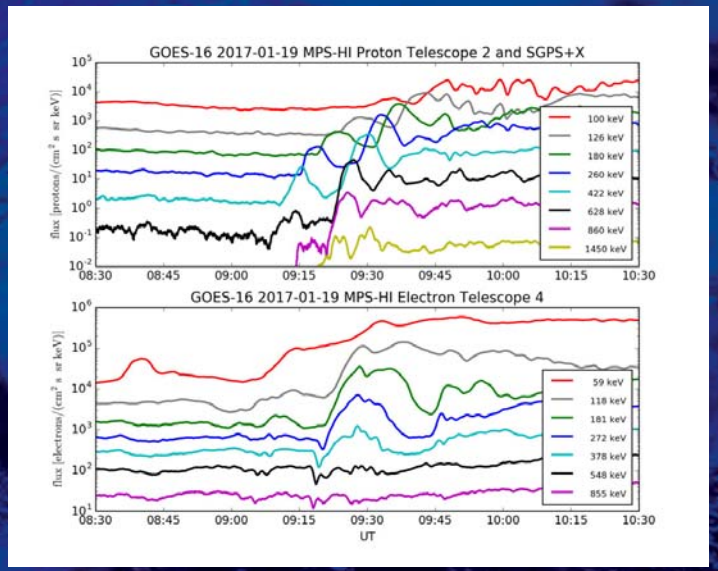
EXIS at the University of Colorado LASP

Space Environment in-Situ Sensor Suite (SEISS)

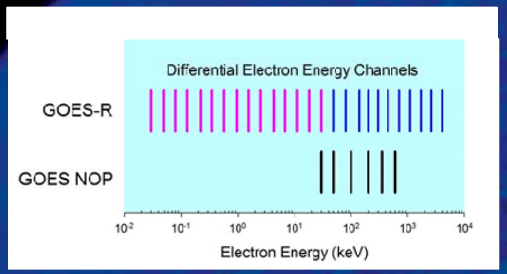
- SEISS consists of energetic particle sensors to monitor proton, electron and alpha particle fluxes
- SEISS provides:
  - More accurate monitoring of energetic particles responsible for radiation hazards to humans and spacecraft
  - Better monitoring of ionizing responsible for spacecraft charging
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

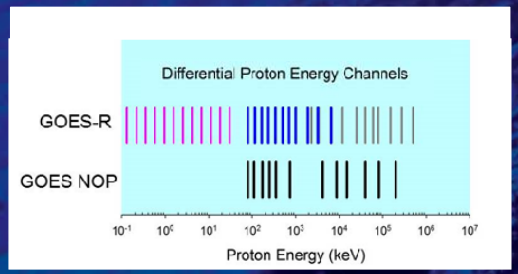
SEISS at Assurance Technology Corp

1st SEISS Data Release



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





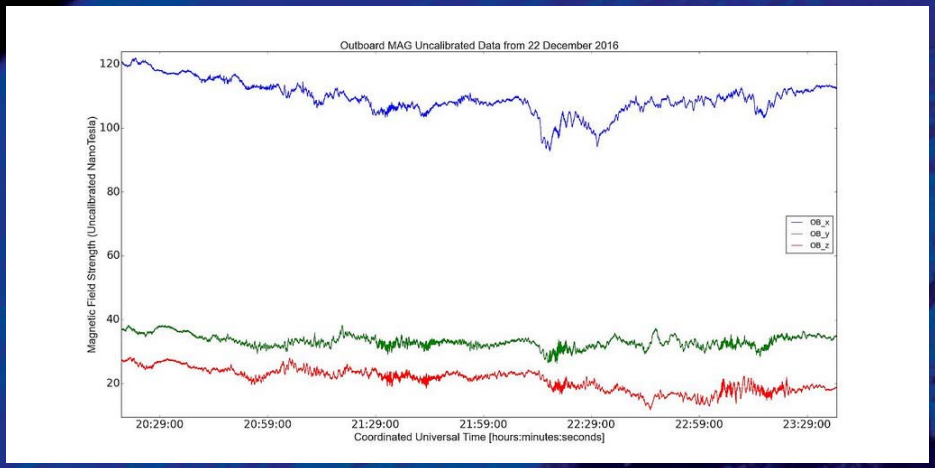
Magnetometer

- 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



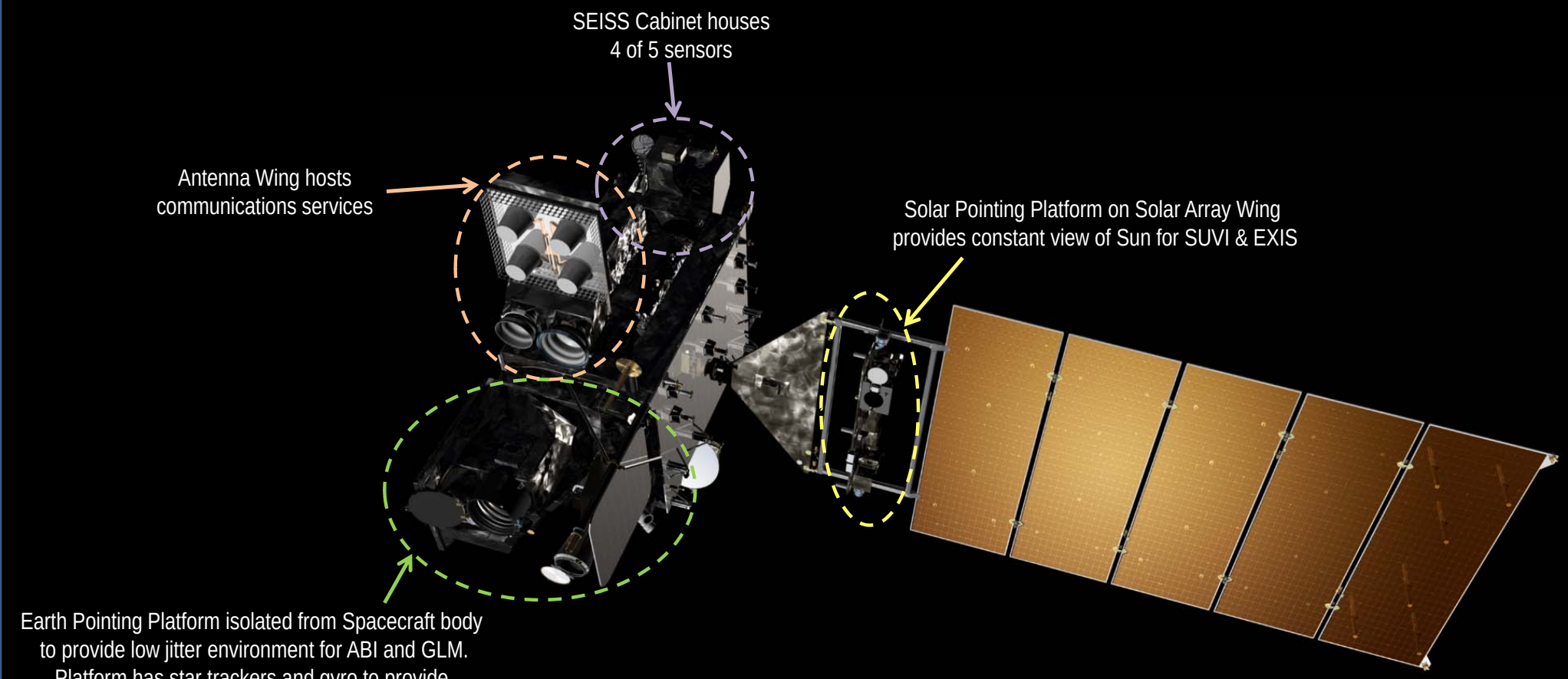
GOES-R Communications Services

- **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



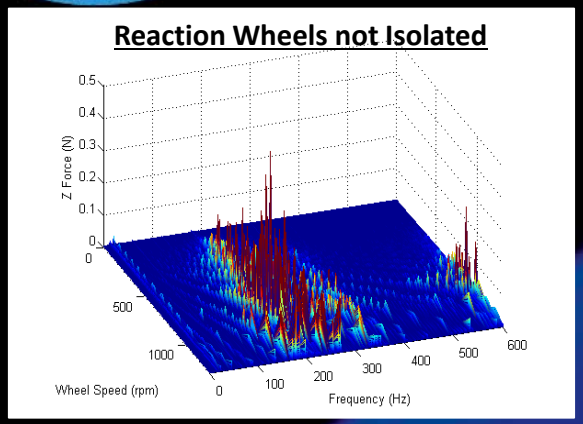
Magnetometer & 5th SEISS sensor on +X panel not shown

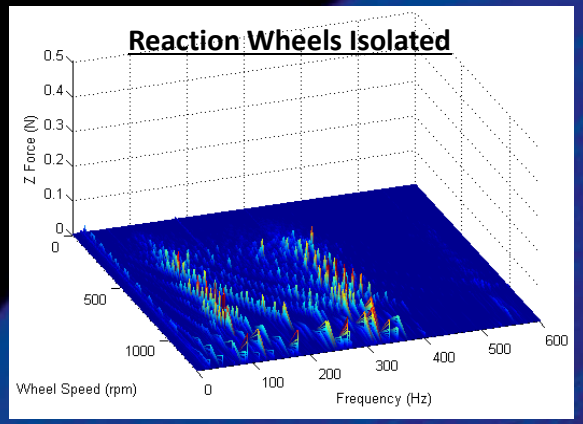
GOES-R Spacecraft Design

- 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

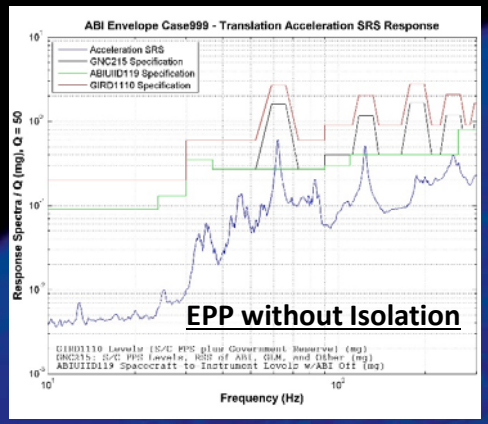
Key GOES-R Space Segment Performance Parameters			
		Requirement	Performance
Pointing	Attiude Knowledge - Diurnal	45µrad 3σ	26µrad 3σ
	Attitude Integrated Rate Error provided to ABI - 1 Sec	1µrad 3σ X&Y, 1.5µ 3σ Z	0.8µrad 3σ
	Attitude Integrated Rate Error provided to ABI - 30 Sec	2µrad 3σ X&Y, 2.5µ 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

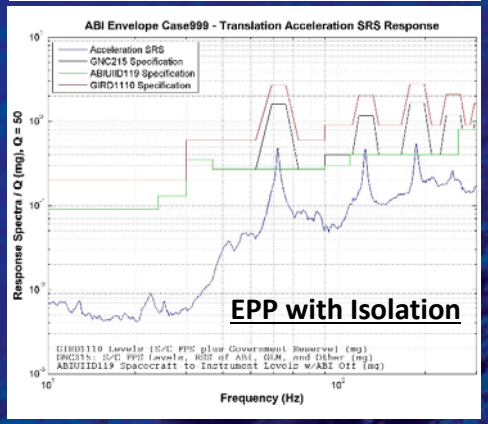
GOES-R Techniques for Stable Pointing



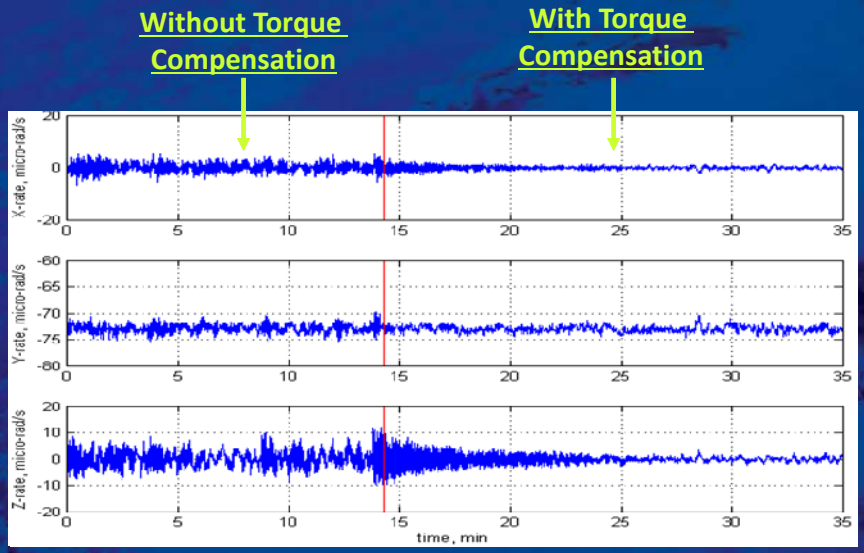


Reaction Wheels Isolation to Minimize Disturbances Transmitted to Spacecraft





Earth Pointing Platform Isolated to Minimize Disturbances to ABI & GLM

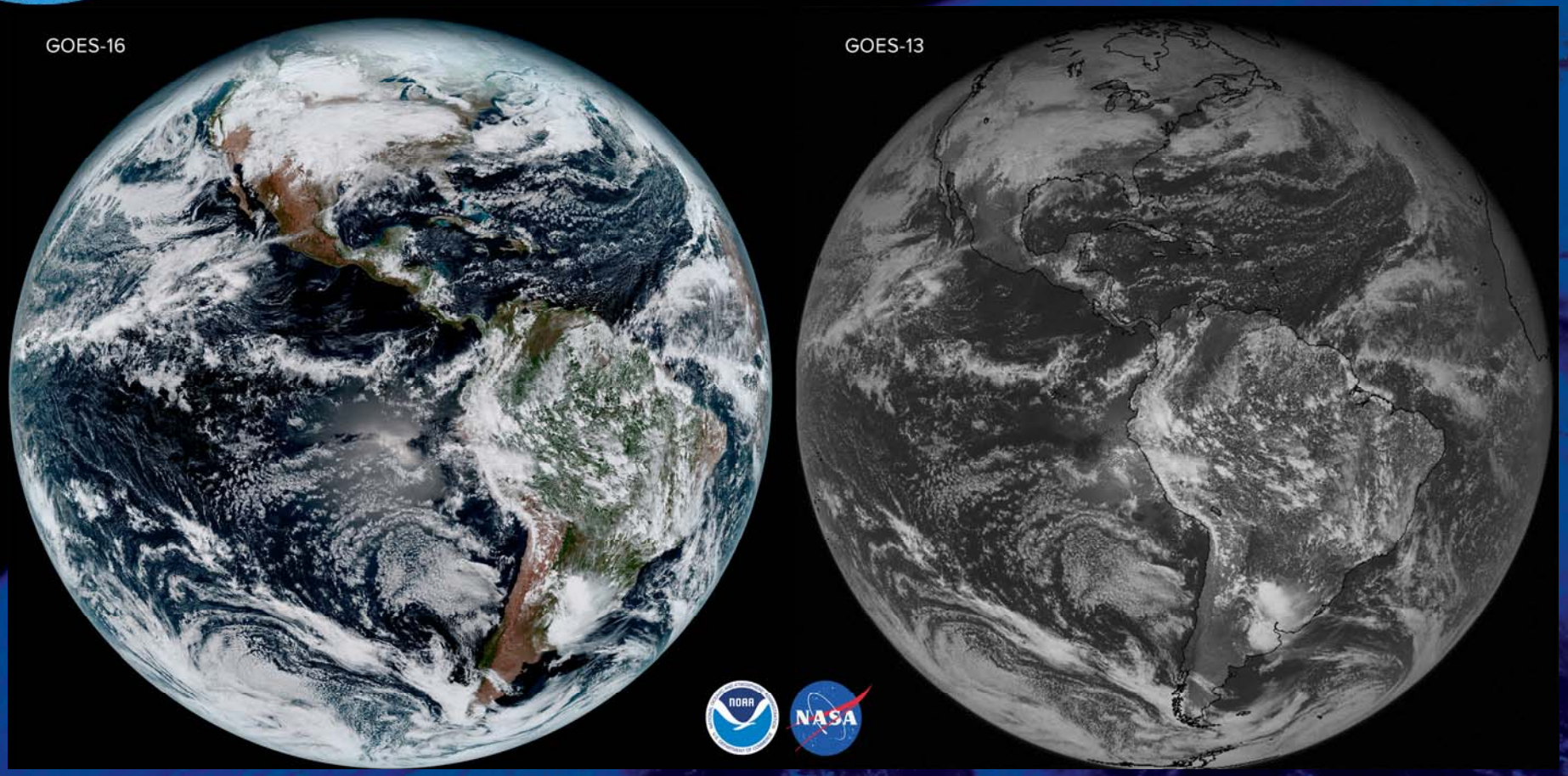


Spacecraft Body Rates during ABI Scanning, before and after Enabling Torque Compensation

GOES-16 Imagery

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

First ABI Public Release

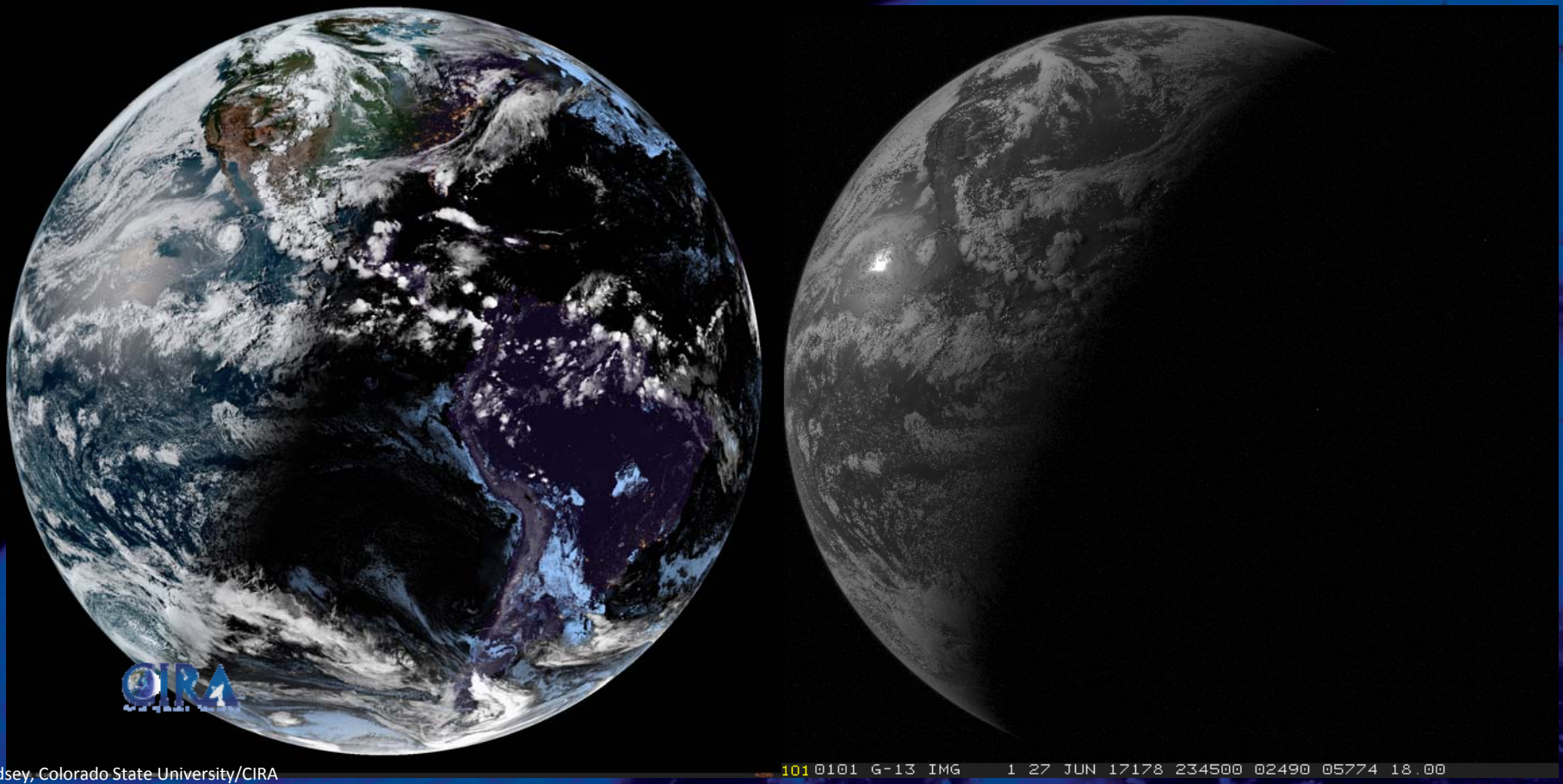


GOES-16 vs GOES-13 on January 15, 2017

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

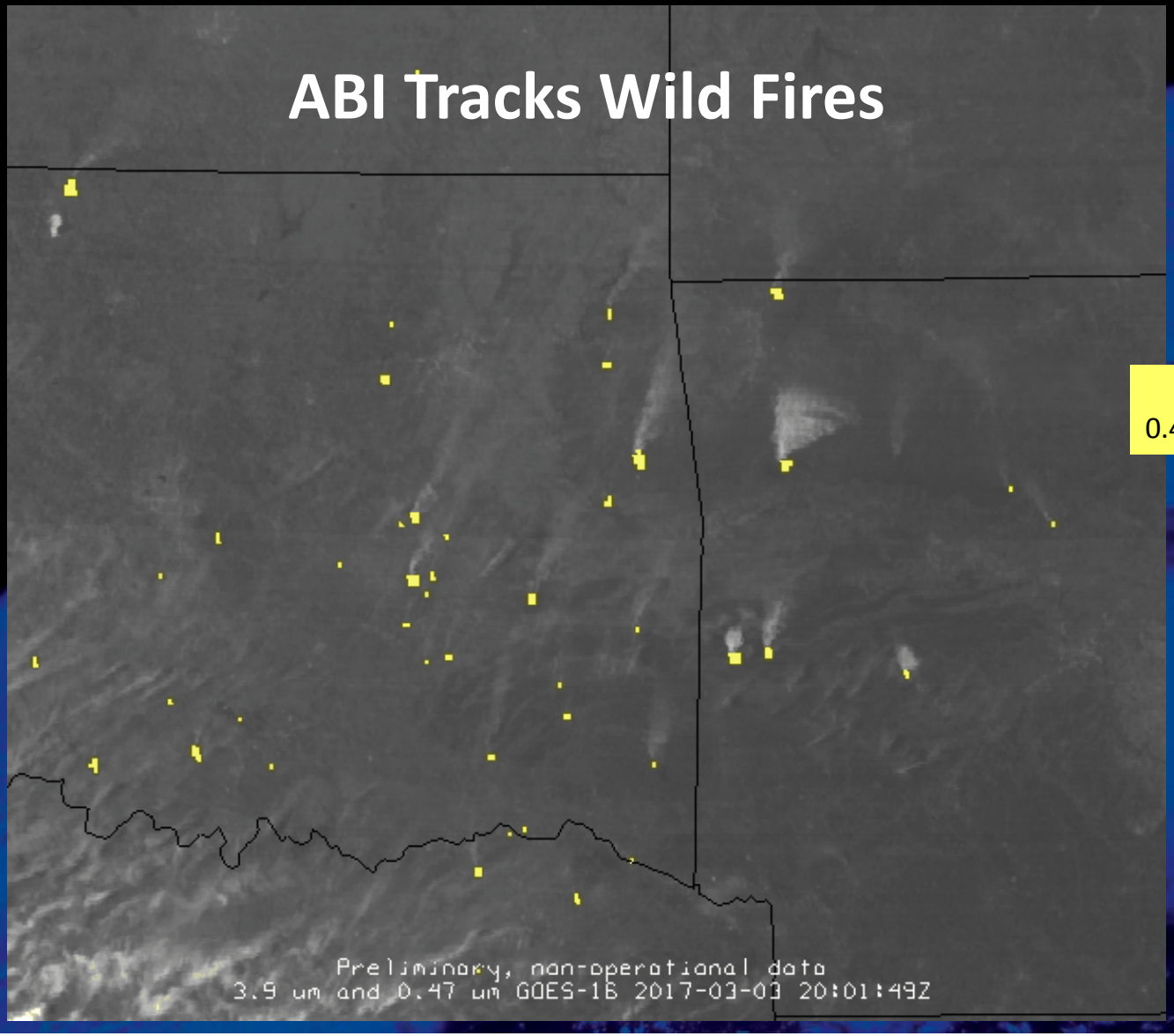
GOES-R every 15 minutes

GOES-N every 3 hours



Courtesy Dan Lindsey, Colorado State University/CIRA

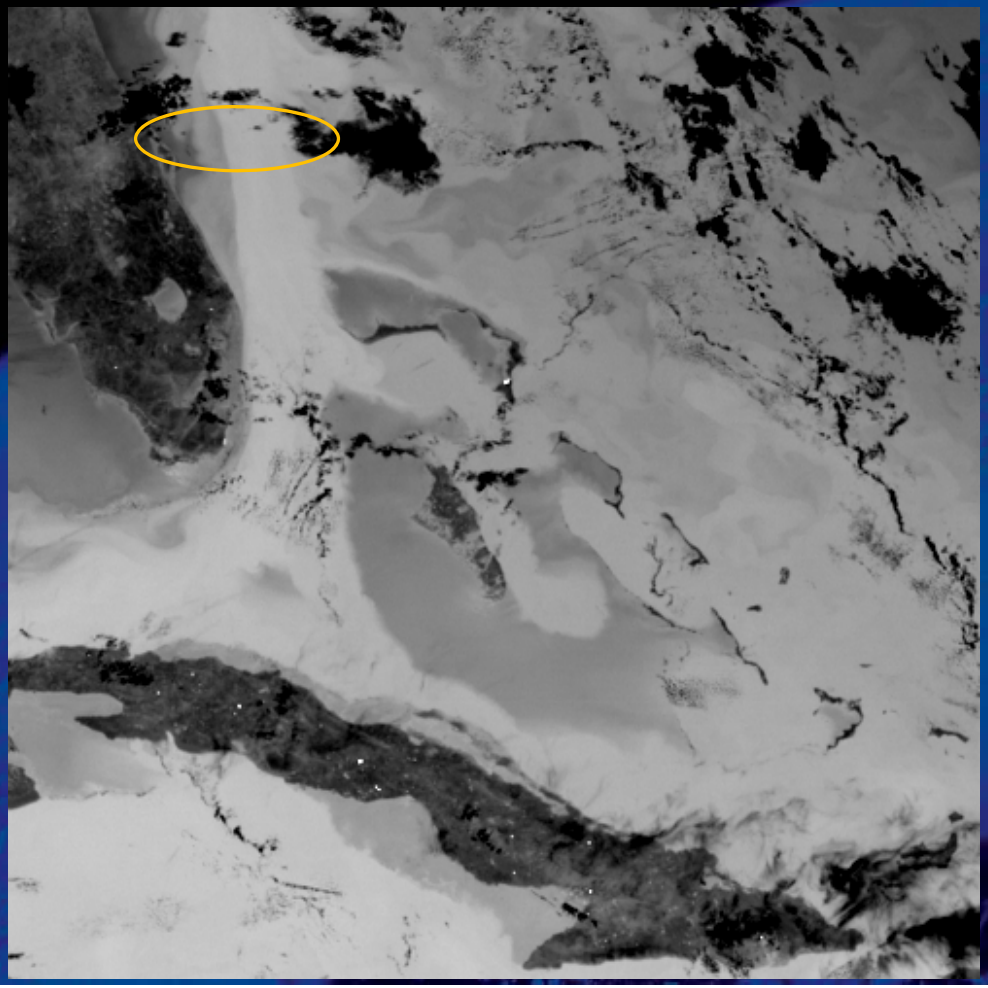
ABI Tracks Wild Fires



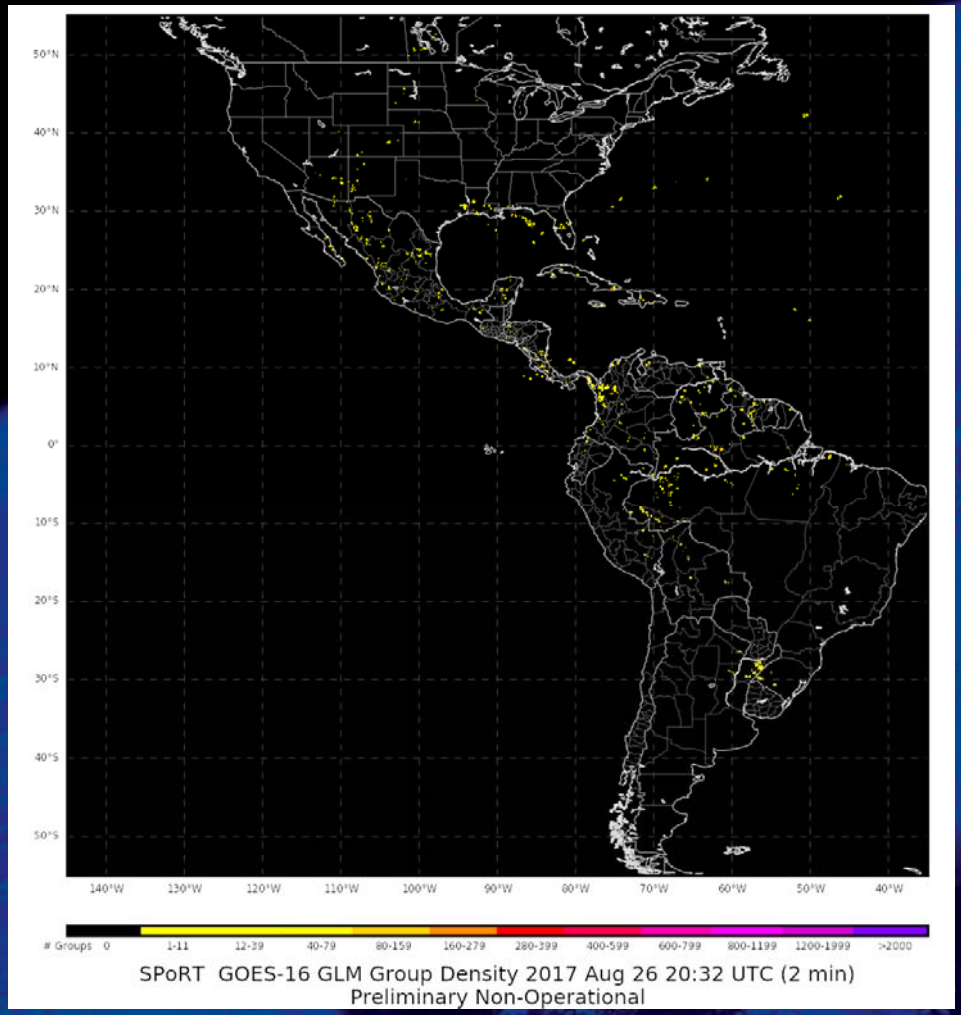
3.9 um (hotspots)
0.47 um (smoke plumes)

Courtesy Bill Line,
National Weather Service

ABI 3.9um Channel Sees Atlas V Launch

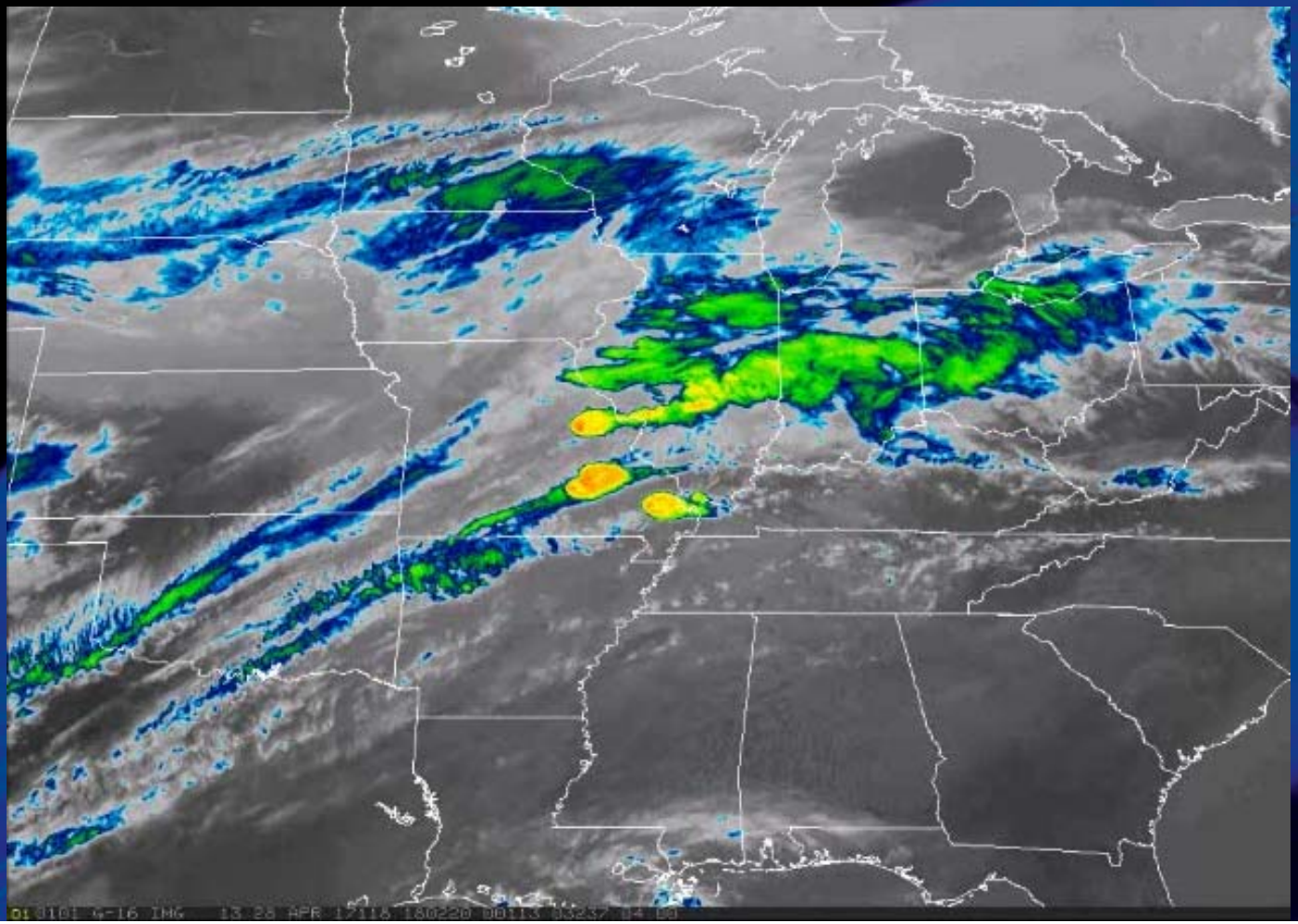


GLM Lightning Map

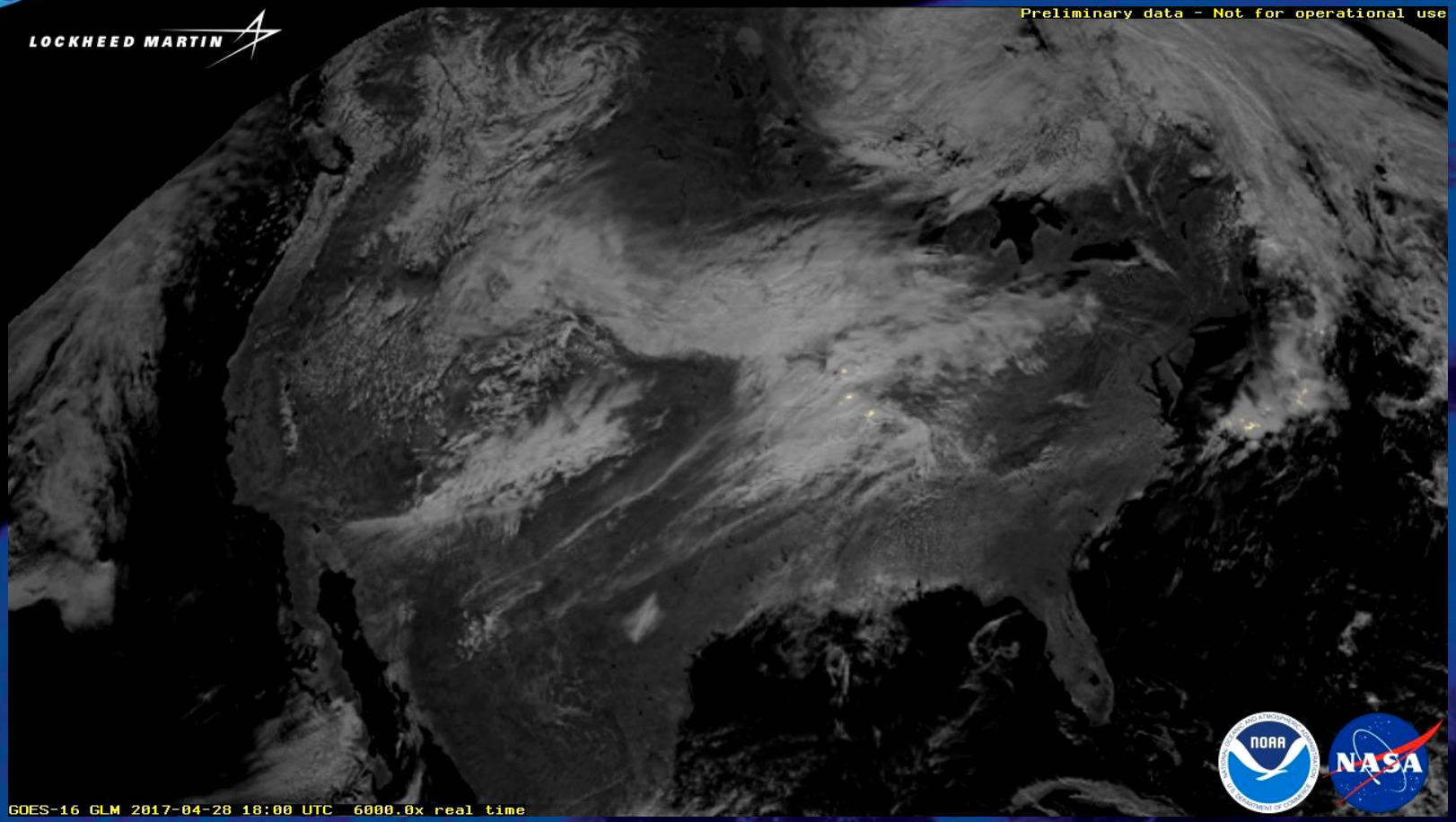


Courtesy NASA Short-term Prediction Research and Transition Center

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



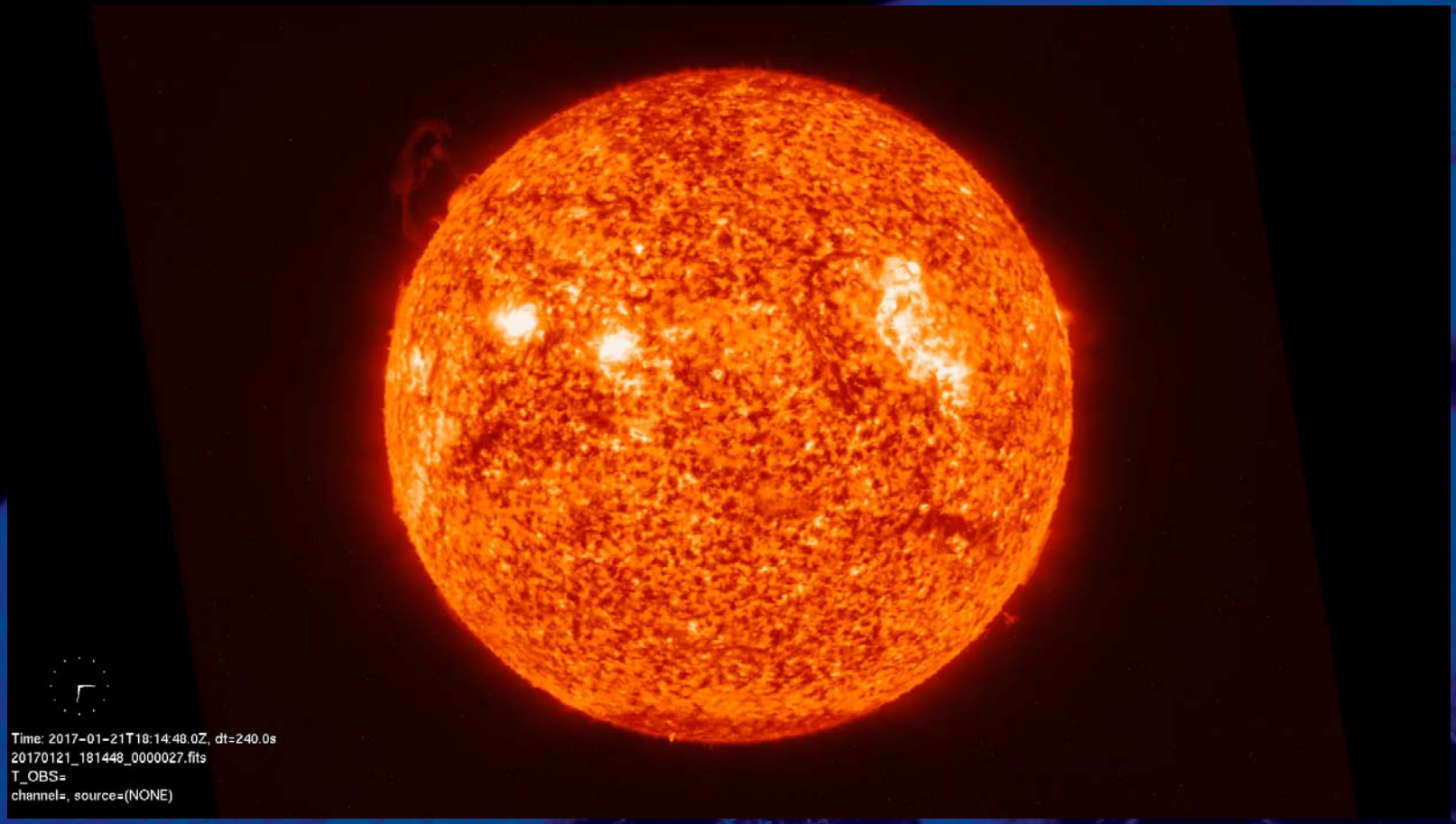
GLM Lightning Detected during Severe Weather in Eastern U.S.



Courtesy Lockheed Martin

GLM lightning superimposed on GLM background

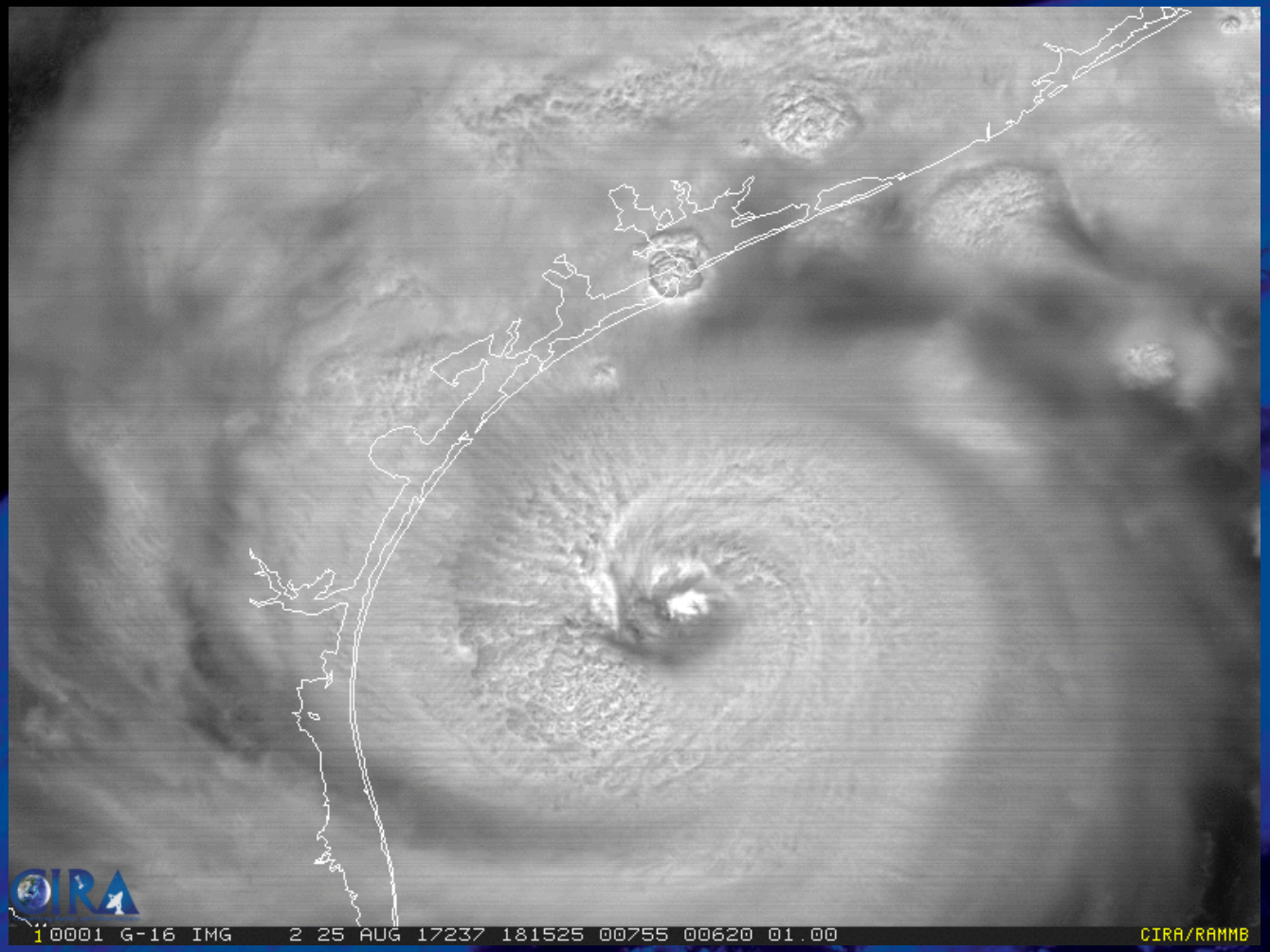
SUVI 304Å Channel



Courtesy
Lockheed Martin

Hurricane Harvey Strikes Texas Coast

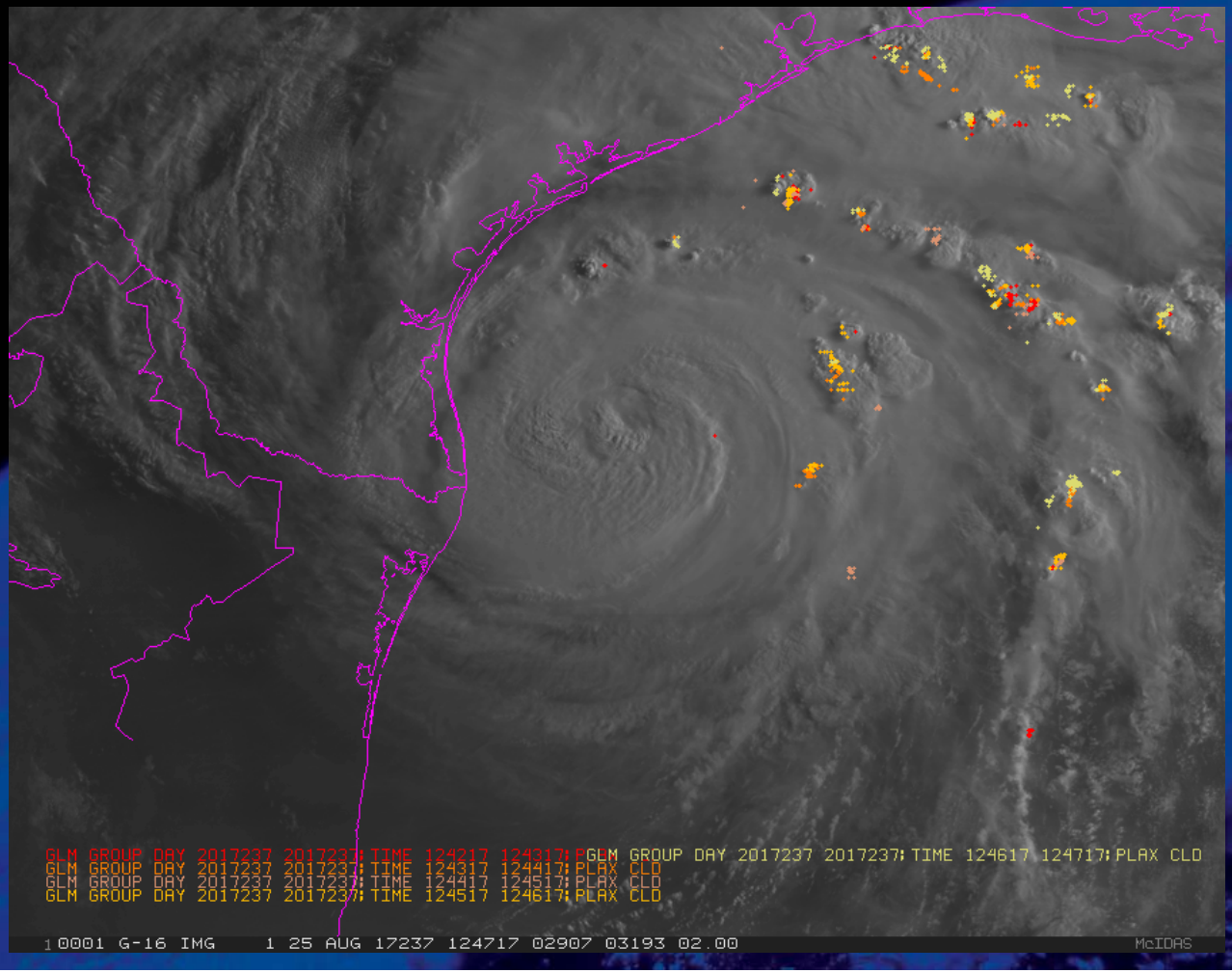
ABI 0.64um



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:

www.goes-r.gov

Twitter.com: #GOES16

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

http://rammb.cira.colostate.edu/ramsdis/online/loop_of_the_day/