New Meteorological and Lightning Instrumentation at Pad 39B Kennedy Space Center, Florida

Dr. C.T. Mata
Team QNA
KSC, FL USA

Table of Contents

Background

LC 39B Lightning Protection System Construction, 2009

Background

Atlantis and Endeavour, 2009

Background

STS-125, Atlantis, May 11 2009

Background

ARES I-X Test Rocket, October 28 2009

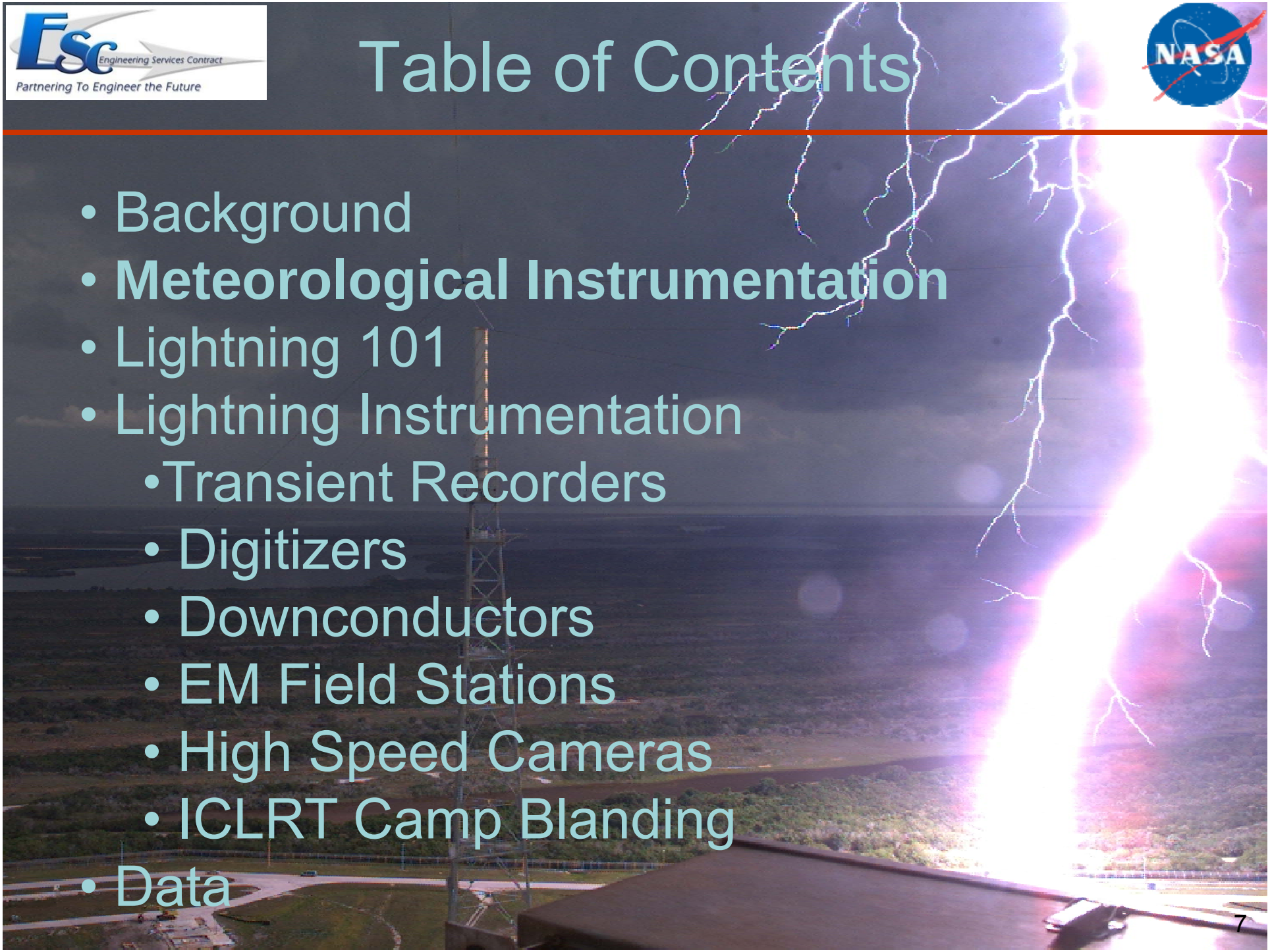
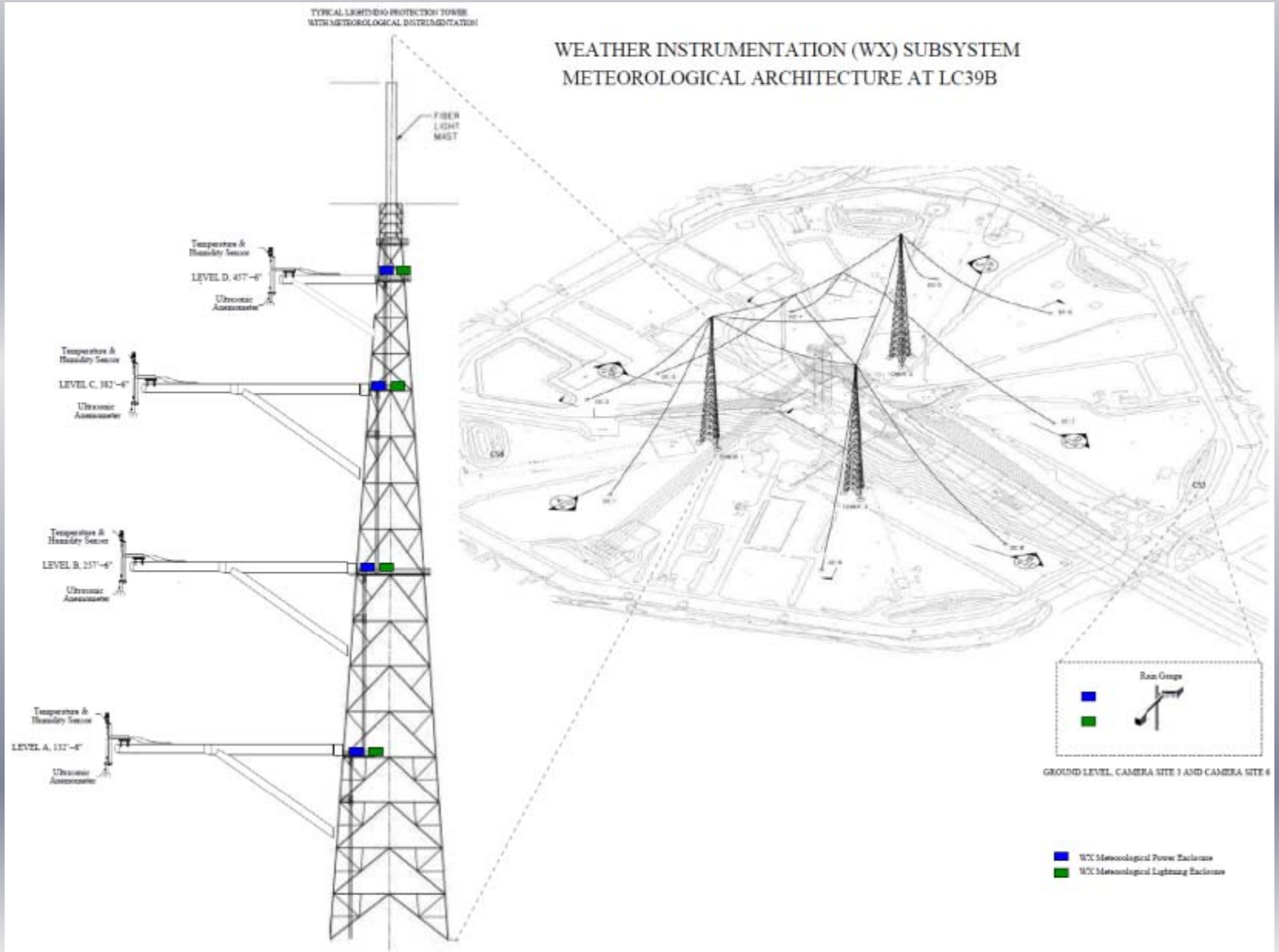


Table of Contents

- Background
- **Meteorological Instrumentation**
- Lightning 101
- Lightning Instrumentation
  - Transient Recorders
  - Digitizers
  - Downconductors
  - EM Field Stations
  - High Speed Cameras
  - ICLRT Camp Blanding
- Data

Meteorological Instrumentation



Meteorological Instrumentation

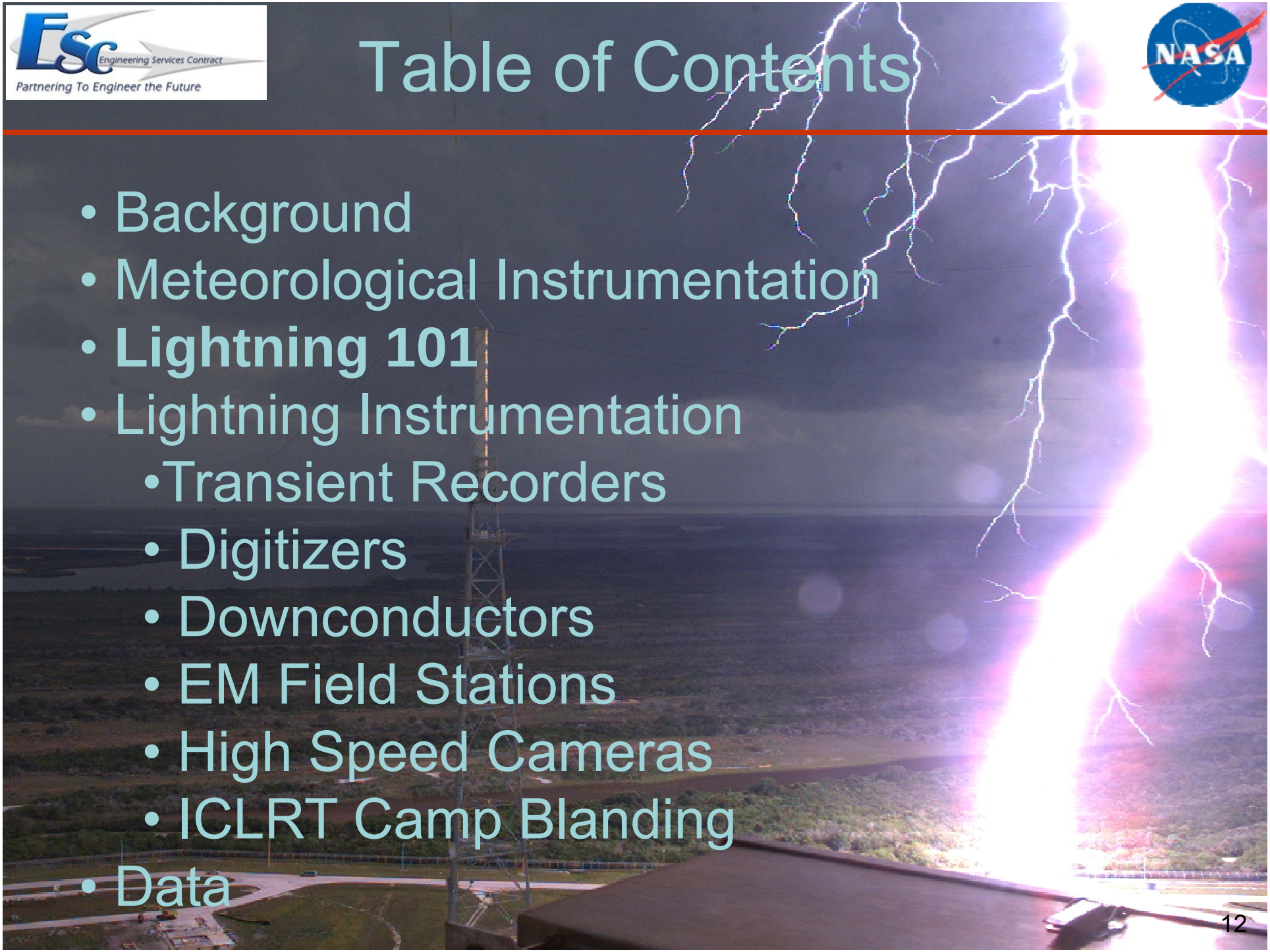
Measurement	Range	Accuracy
Wind Speed	0.0 to 60 m/s	± 2% up to 25 m/s
Wind Direction	0 to 359 degrees	± 2 degrees
Air Temperature	-10 to 50 deg Celsius	0.1 deg Celsius (NIST traceable)
Relative Humidity	0 to 100 %	3% (from 10 to 90% RH)
Rain Rate	0 to 19.685 inches/hour	5% Accumulation
Rain Precipitation Accumulation	0 to 39.37 inches	5% Accumulation

Meteorological Instrumentation

- Meteorological stations (CS CR1000):
  - Battery backed up
  - GILL Instruments HS WindObserver
    - 0-75 m/s (0-168 mph)
    - 0.01 m/s resolution
    - 0-12 m/s +/- 1%; 12-25 m/s +/- 2%; 25-45 m/s +/- 3%; 45-65 m/s +/- 4%; 65-80 m/s +/- 6%
    - Resolution of 1º and accuracy of +/- 2º @ 12 m/s, no dead band
  - R.M. Young 41372VC/VF with aspirated shield
    - Temperature range -10 to 60ºC, accuracy +/- 0.1º
    - RH range 0-100%, accuracy 3%
  - Optical Rain Gauge OSI ORG-815-DS
    - Range 0.1 to 500 mm/hr, resolution 0.001 mm, accuracy 5% accumulation,

Meteorological Instrumentation

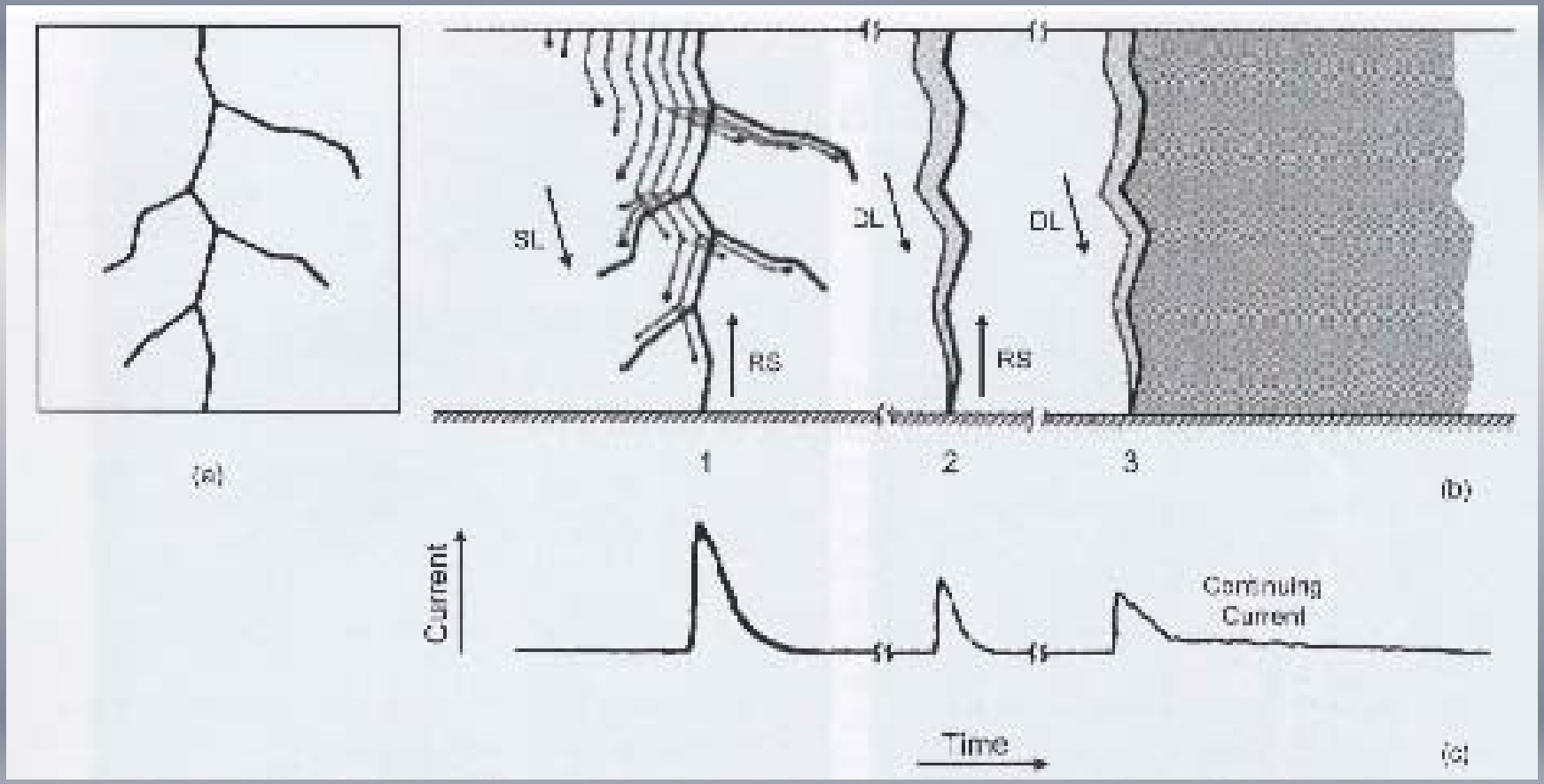
Table of Contents



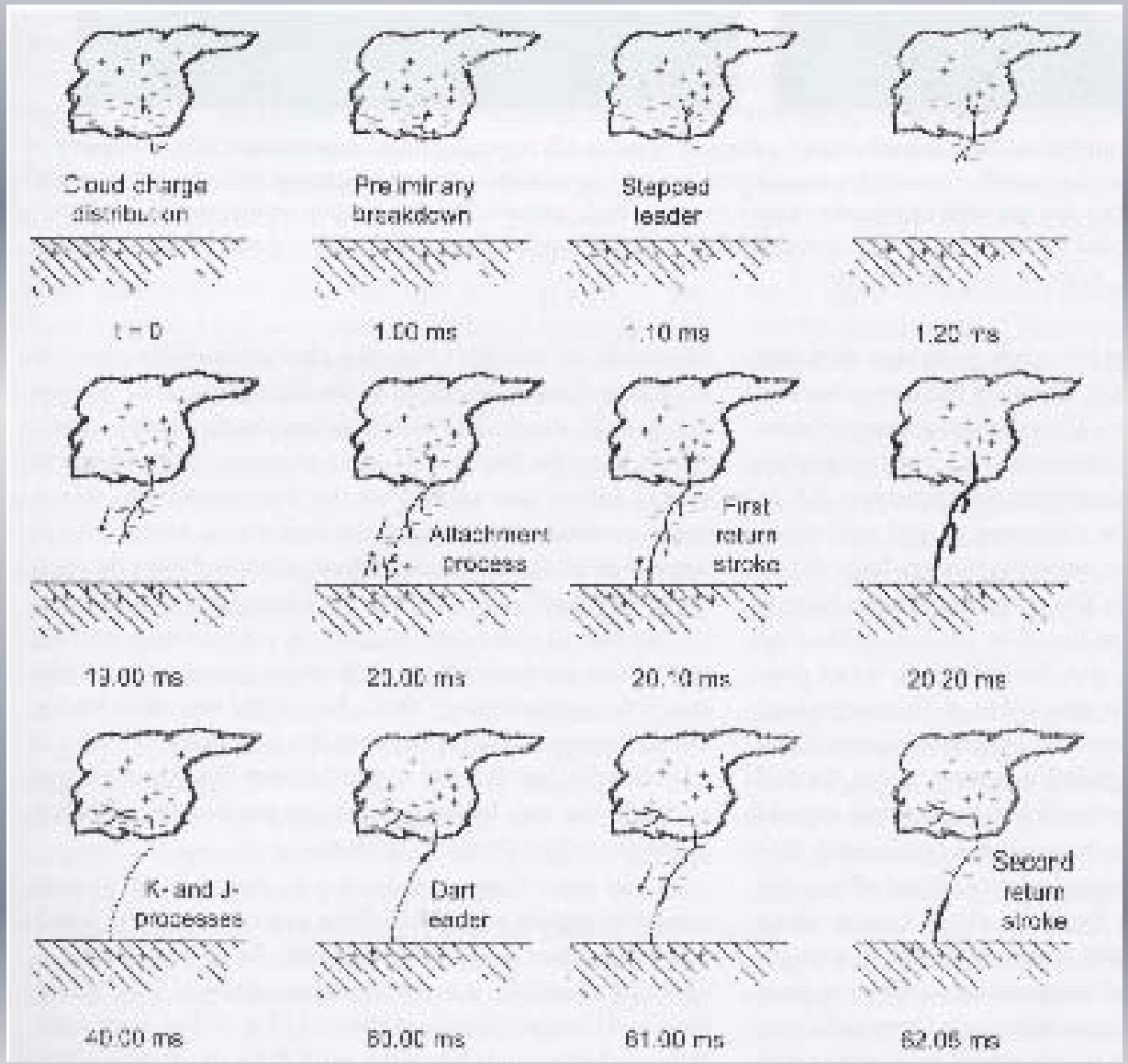
- Background
- Meteorological Instrumentation
- **Lightning 101**
- Lightning Instrumentation
  - Transient Recorders
  - Digitizers
  - Downconductors
  - EM Field Stations
  - High Speed Cameras
  - ICLRT Camp Blanding
- Data

Lightning 101

- What is a flash? What is a stroke?

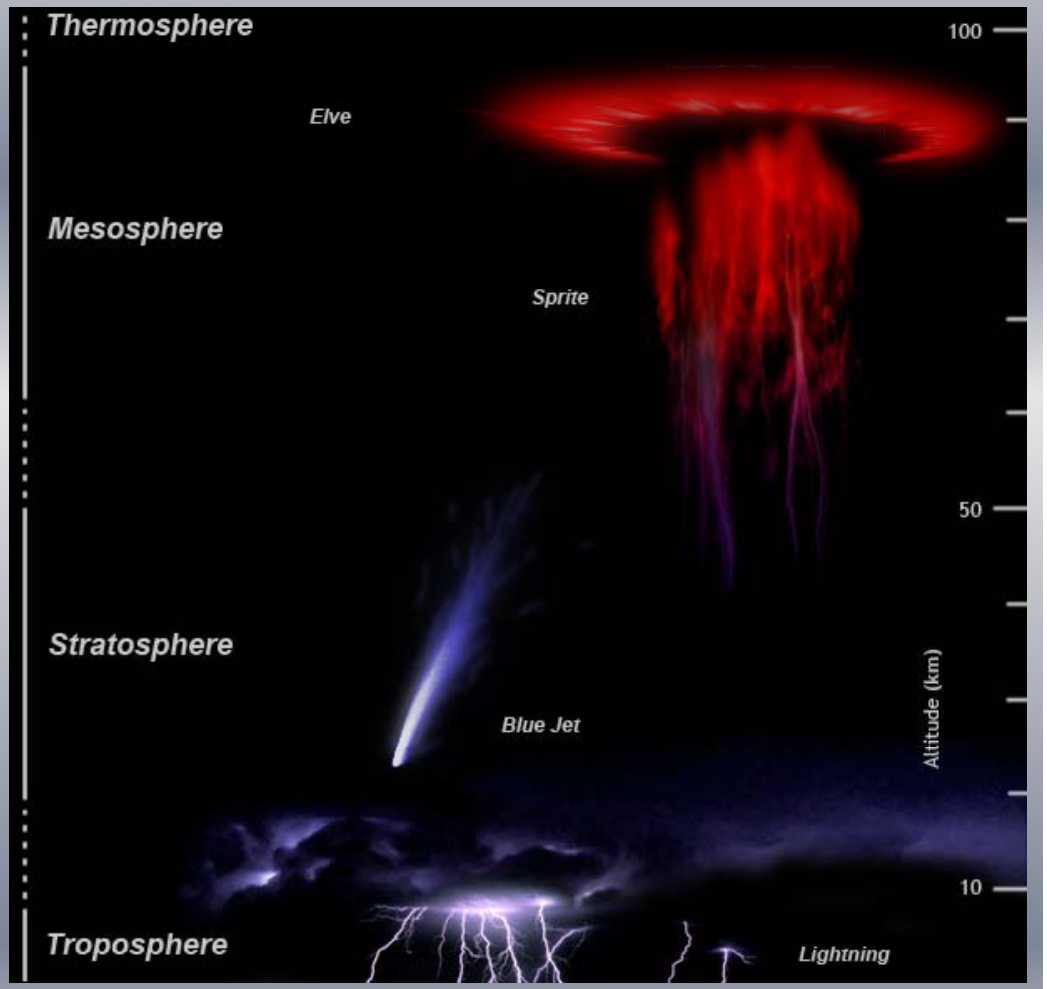


Lightning 101



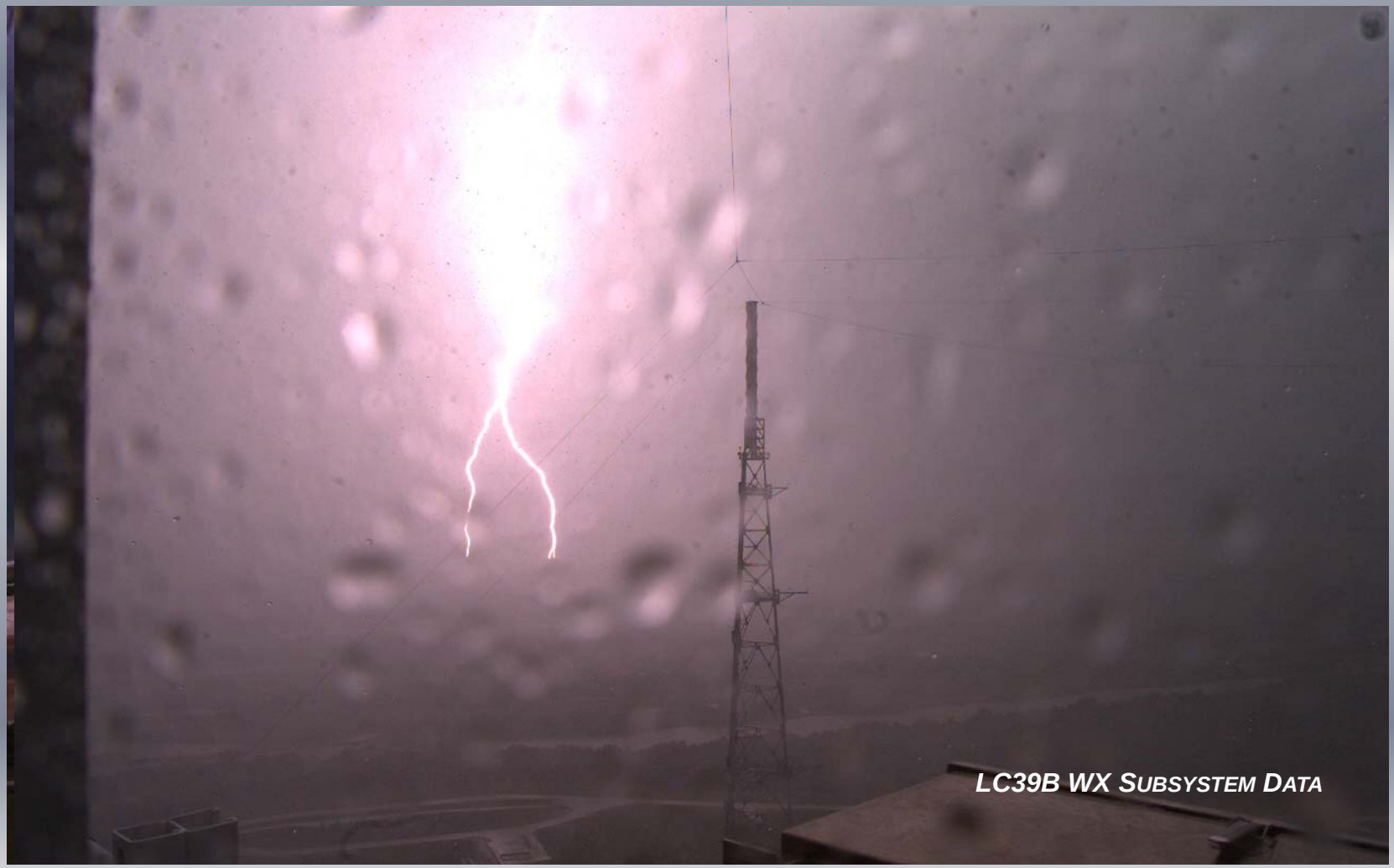
Lightning 101
How many different types of lightning?

- Upper Atmosphere, or TLE:
blue jets, gigantic jets, sprites, sprite halo, elves, etc.
- Lower Atmosphere:
cloud to cloud, cloud to ground, ground to cloud, upward, downward, ball, spider, triggered, positive, negative, volcanic, etc.



Lightning 101

- Can lightning strike more than one location simultaneously?



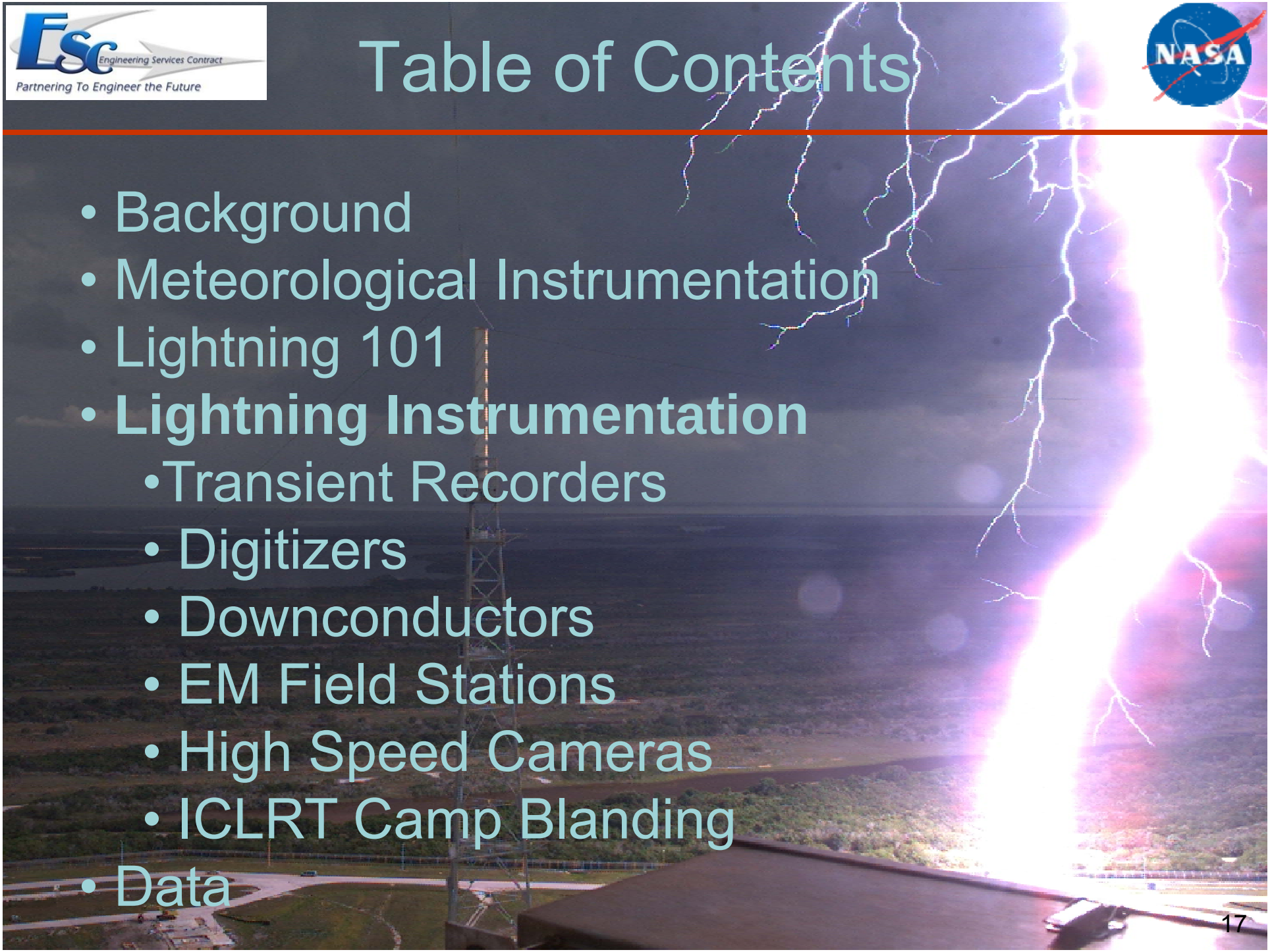


Table of Contents

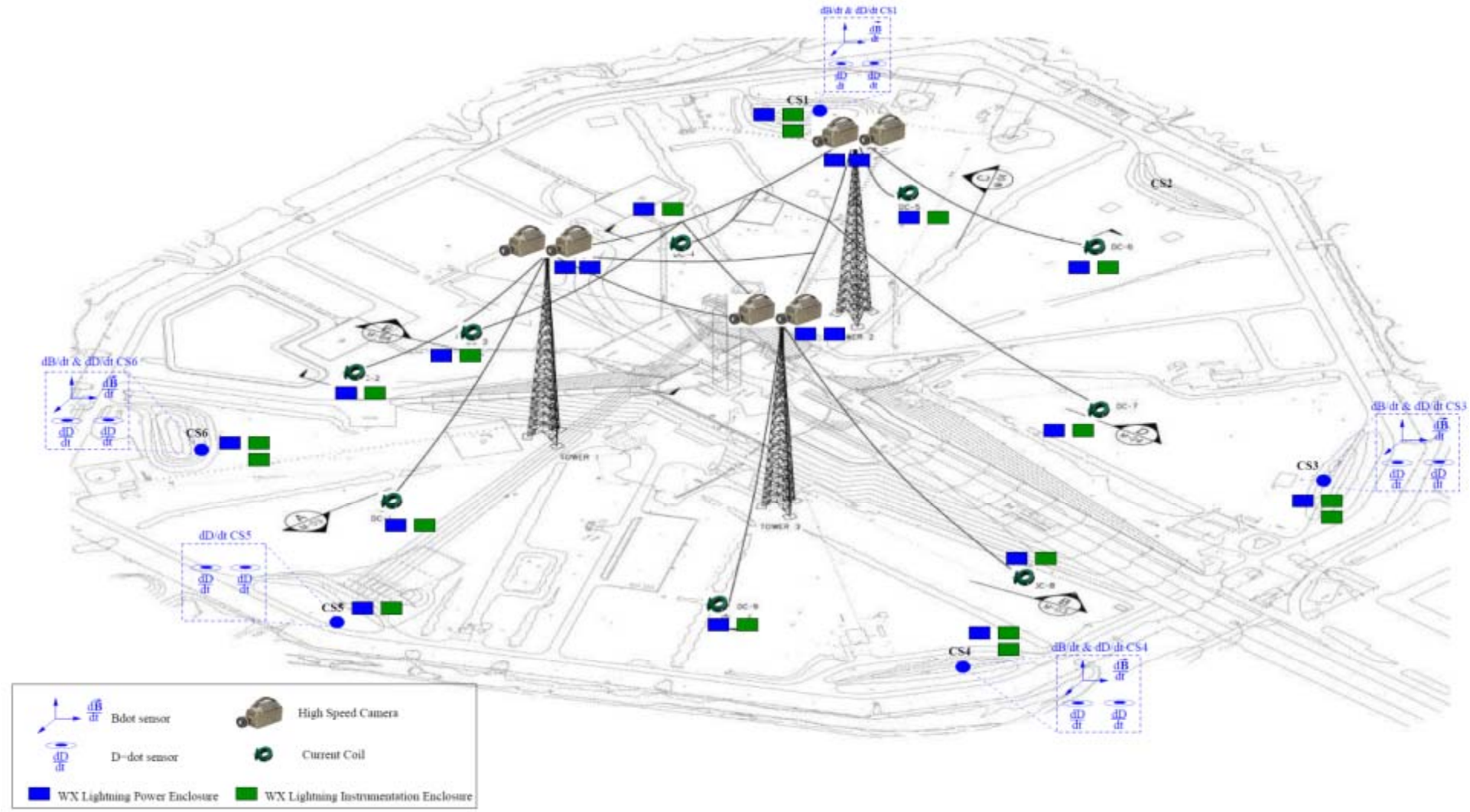
- Background
- Meteorological Instrumentation
- Lightning 101
- **Lightning Instrumentation**
  - Transient Recorders
  - Digitizers
  - Downconductors
  - EM Field Stations
  - High Speed Cameras
  - ICLRT Camp Blanding
- Data

Lightning Instrumentation Requirements

- Immune to lightning strikes
- High detection efficiency ≈100%, no dead time
- Highly Accurate:
  - ≈95%, error < 2 meters (High Speed Cameras)
  - ≈5%, error < 5 – 10 meters (Ddot & Hdot Sensors)
- Commercial Off-The-Shelf (COTS),
  - Transient Recorders*,
  - Digitizers*,
  - Current Sensors
  - Bdot and Ddot Sensors*,
  - High Speed Cameras*,
- Custom made,
  - Power conditioning: racks and enclosures,
  - High Speed Camera Trigger Chassis

Lightning Instrumentation

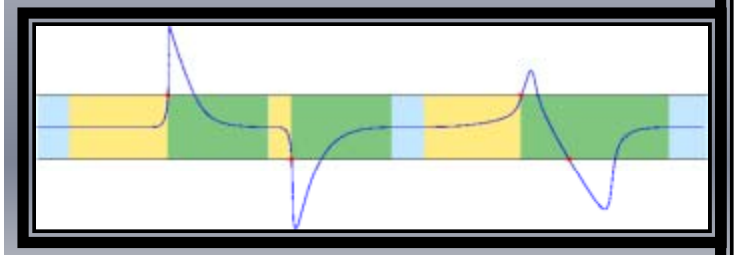
Lightning Instrumentation Architecture

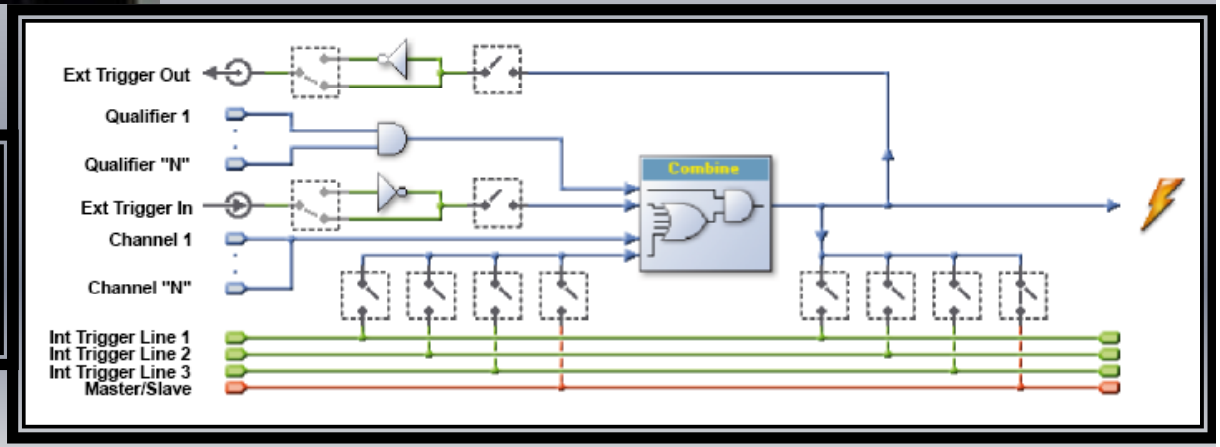


Lightning Instrumentation

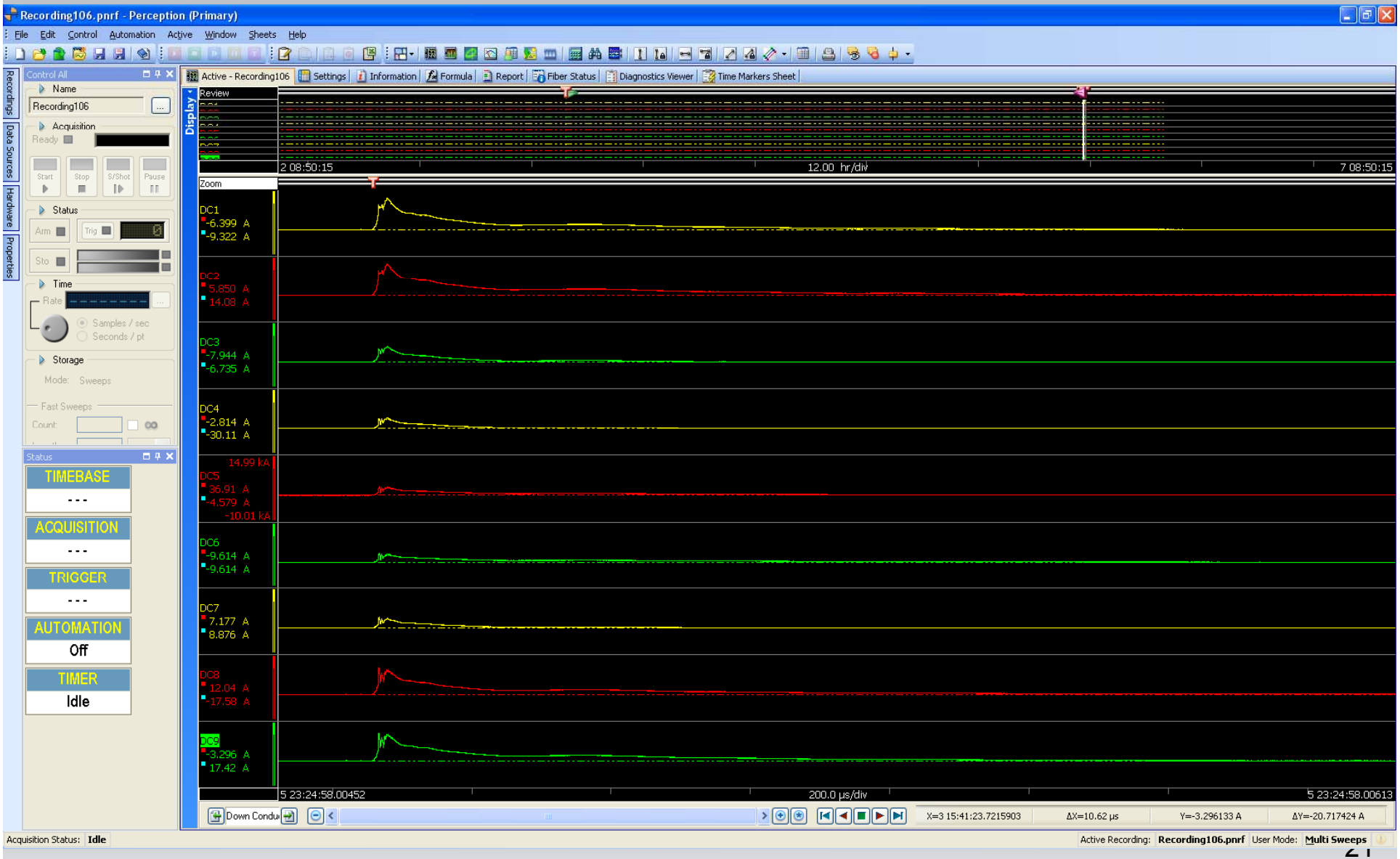
Genesis Transient Recorder, HBM (Nicolet)

- FIFO, computer data transfer,
- Segmented Memory, no dead time
- 100 Megasamples/sec,
- Single mode fiber interface with time propagation delay compensation,
- Comprehensive triggering capabilities: stretch trigger option,
- Master/Slave (shared trigger bus),
- Automated waveform exports,
- 60 channels/chassis x 8 chassis, 10 ns





Perception


Recording106.pnrf - Perception (Primary)
File Edit Control Automation Active Window Sheets Help
Control All
Name
Recording106
Acquisition
Ready
Start Stop S/Shot Pause
Status
Arm Trig
Sto
Time
Rate
Samples / sec
Seconds / pt
Storage
Mode: Sweeps
Fast Sweeps
Count:
Status
TIMEBASE

ACQUISITION

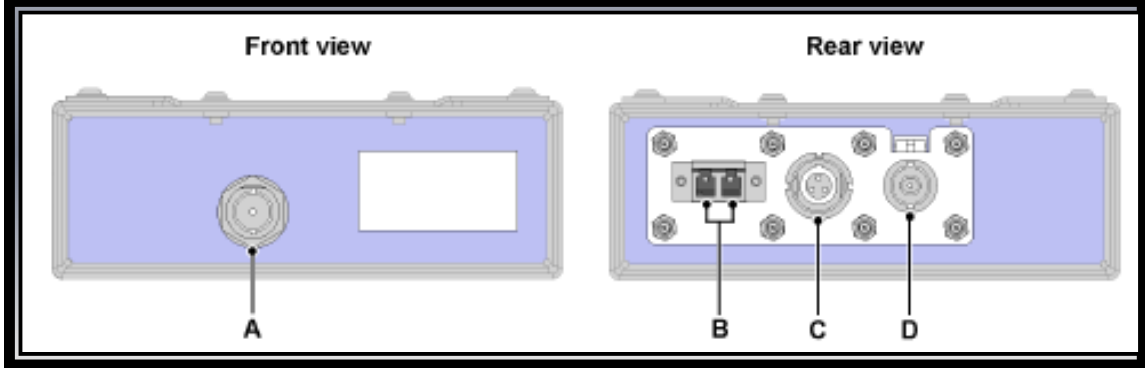
TRIGGER

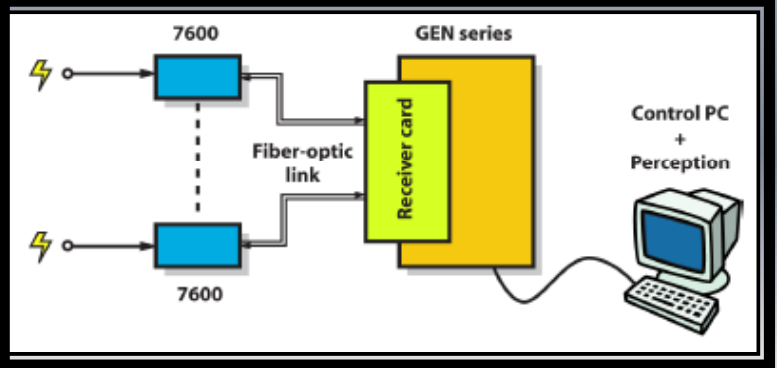
AUTOMATION
Off
TIMER
Idle
Active - Recording106
Settings
Information
Formula
Report
Fiber Status
Diagnostics Viewer
Time Markers Sheet
Display
Review
2 08:50:15
12.00 hr/div
7 08:50:15
Zoom
DC1
-6.399 A
-9.322 A
DC2
5.850 A
14.08 A
DC3
-7.944 A
-6.735 A
DC4
-2.814 A
-30.11 A
14.99 kA
DC5
36.91 A
-4.579 A
-10.01 kA
DC6
-9.614 A
-9.614 A
DC7
7.177 A
8.876 A
DC8
12.04 A
-17.58 A
DC9
-3.296 A
17.42 A
5 23:24:58.00452
200.0 µs/div
5 23:24:58.00613
X=3 15:41:23.7215903
ΔX=10.62 µs
Y=-3.296133 A
ΔY=-20.717424 A
Acquisition Status: Idle
Active Recording: Recording106.pnrf
User Mode: Multi Sweeps

Digitizer

Ruggedized 7600 Digitizer, HBM (Nicolet)

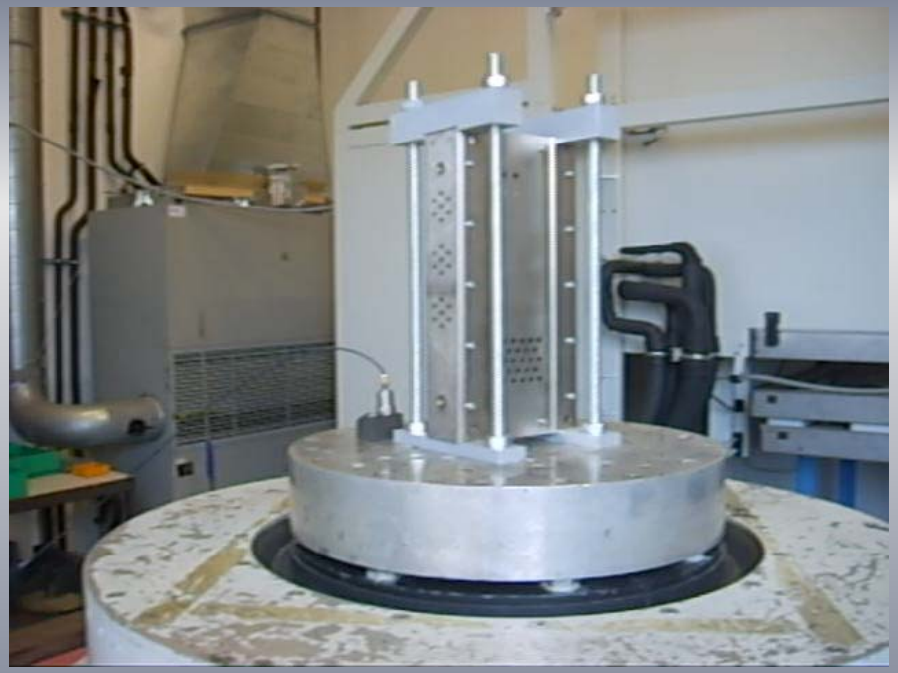
- 12 VDC ± 20% 550 mA maximum
- 100 MS/sec, 25 MHz @ -3 dB, sync sampling
- Coupling AC/DC/GND/Reference
- ± 20 mV to ± 100 V Full Scale in 1, 2, 5 steps, 14 bits
- Temperature range: -10 ºC to +70 ºC
- Max Error: 1% DC to 5 MHz throughout Temp range
- Prototyped and tested at the ICLRT during the 2009, 2010, and 2011 campaigns
- **(A)** single-ended, isolated common input; **(B)** LC Duplex, 1310 nm, 4 km typ, 12 km max; **(C)** Power input; and **(D)** control output.





Digitizer

Ruggedized 7600 Digitizer, LDS Instrumentation (Nicolet), HBM



Digitizer

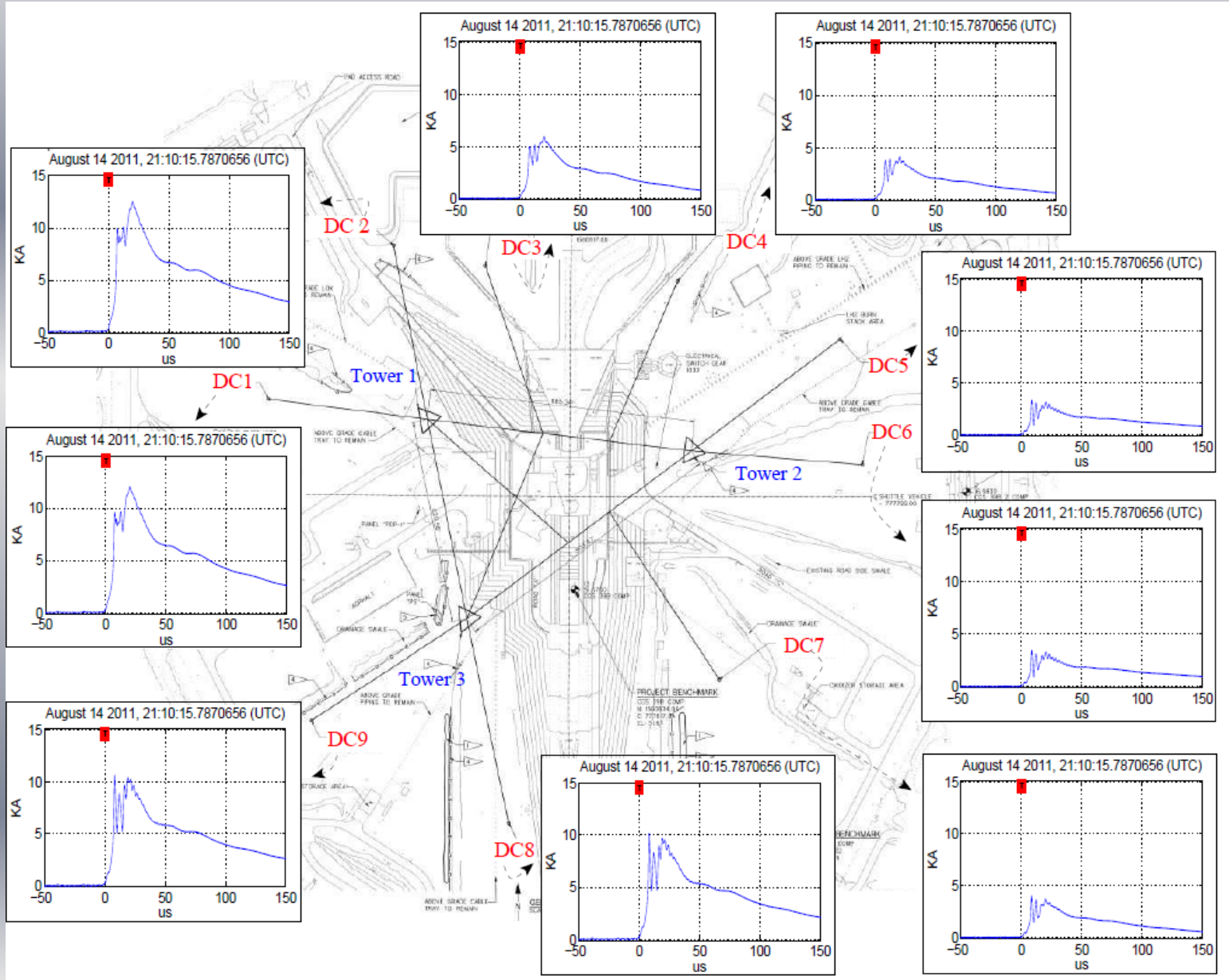
Ruggedized 7600 Digitizer, LDS Instrumentation (Nicolet), HBM

Downconductors

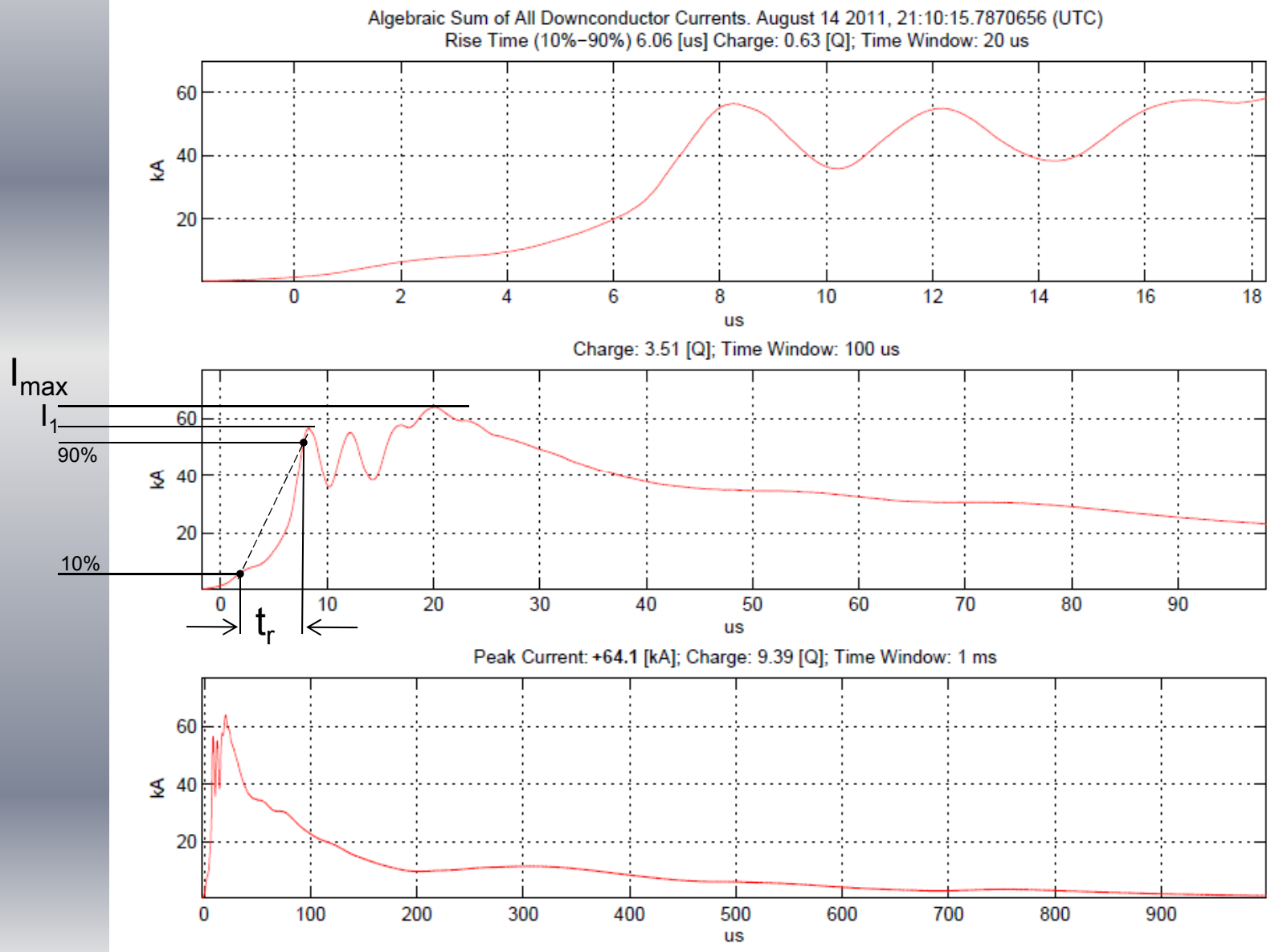
- Pearson Electronics 1330
- Usable rise-time: 250 ns
- 0.9 Hz to 1.5 MHz
- Maximum peak current 100 kA
- Current time product 65 A-s
- 23 MHz anti-aliasing filters

Downconductors

Why Downconductor Measurements?



Why Downconductor Measurements?

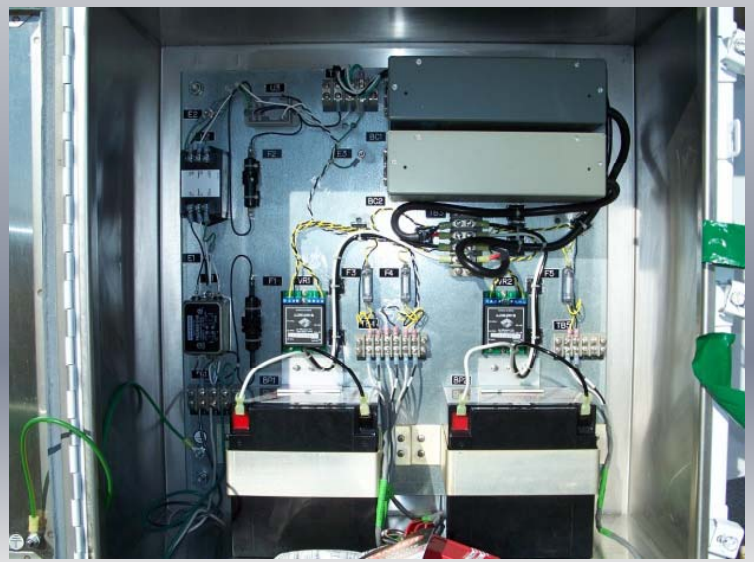


Bdot Field Stations

Four Stations with 3 Axis Bdot Sensors Each

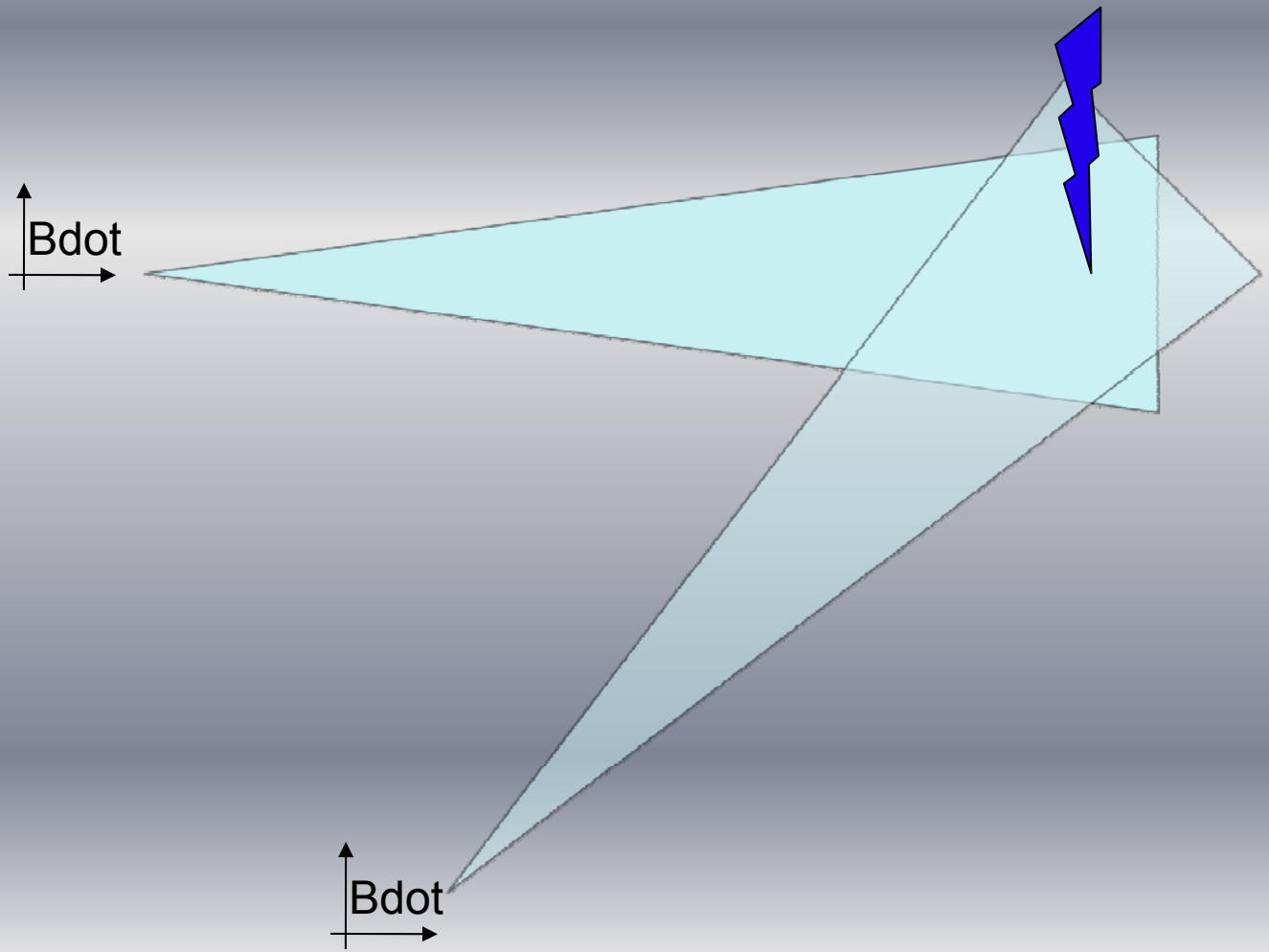
- EG&G MGL-2 Bdot free field sensors,
- 100 Ω, differential twinaxial output, ≈ 300 MHz @ -3dB
- Balun to convert 100 Ω differential to 50 Ω, single mode,
- 23 MHz anti-aliasing filters,
- $A_{eq} = 1x10^{-2}$ m^2 ($V_{out} = A_{eq}$ x dB/dt),
- Max field change of $2x10^5$ Tesla/sec,
- Protected by a fiberglass dome,

Bdot Field Stations



Why Bdot Sensors?

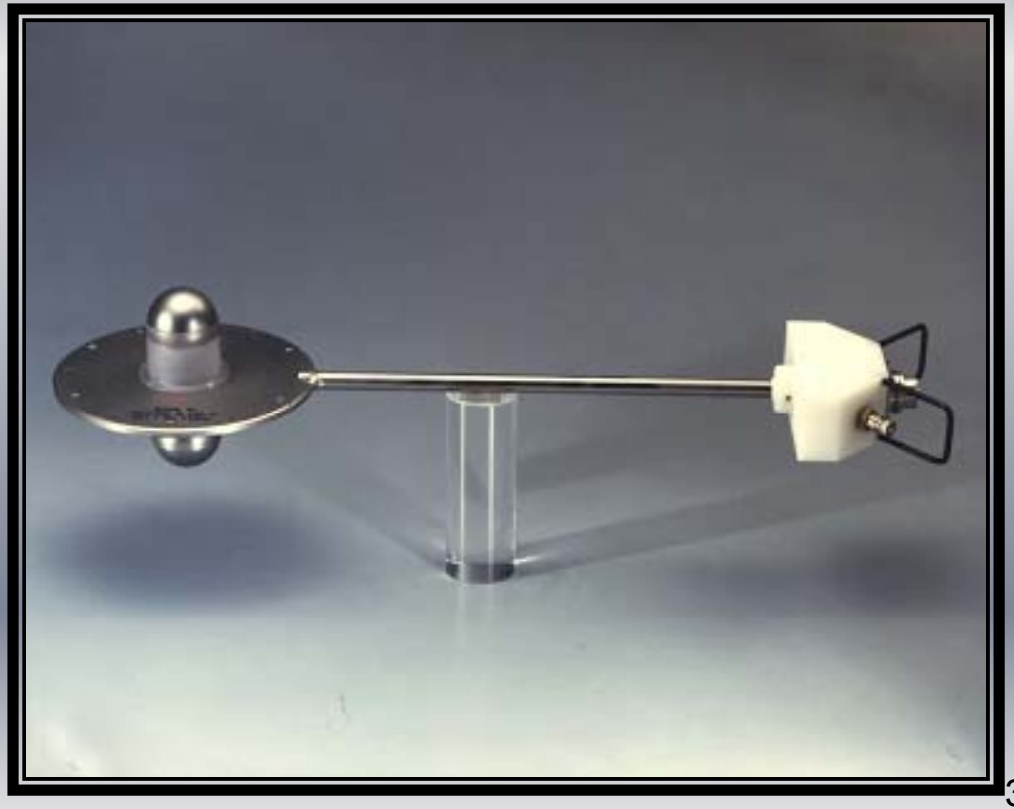
- Estimate Peak Current and Rate of Change of Peak Currents for nearby events,
  - Ampere's Law
- Locate Lightning Strikes, 2 stations with 3 axis allows for 3D location



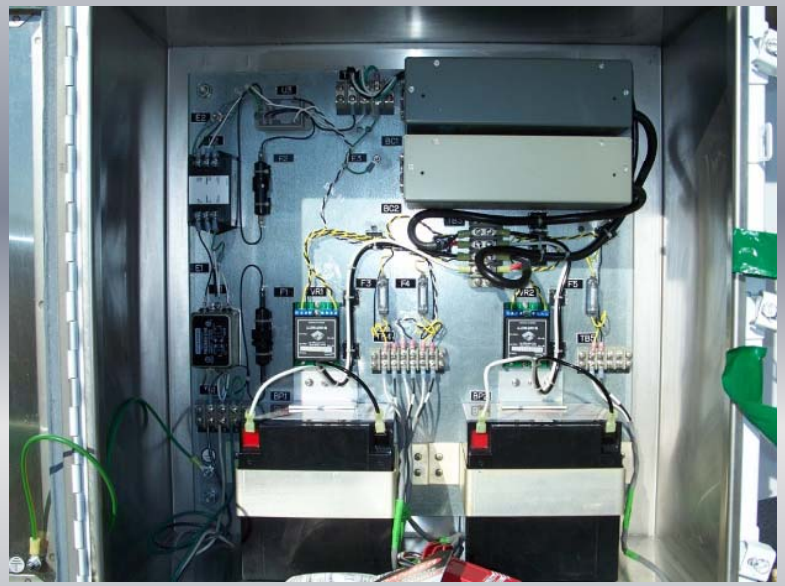
Ddot Field Stations

Five Stations with 2 Ddot Sensors Each

- EG&G? Prodyne?
- 100 Ω, differential twinaxial output, ≈ 1 GHz @ -3dB
- Balun to convert 100 Ω differential to 50 Ω single mode,
- 23 MHz anti-aliasing filters,
- A_{eq} = 1x10^{-2} m^2 (V_{out} = R x A_{eq} x dD/dt),

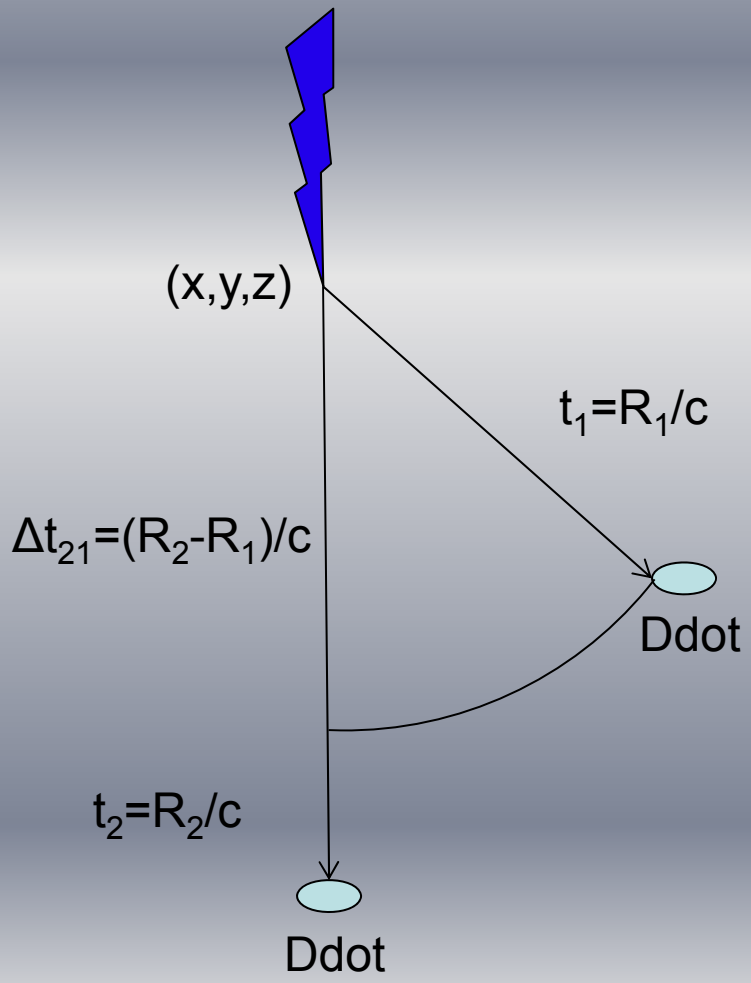


Ddot Field Stations



Why Ddot Sensors?

- Locate Lightning Strikes, time difference of arrival, correlation,
- Four unknowns, (x,y,z) and t
- More than four stations to have an over-determined system of linear equations



Instrumentation

High Speed Cameras, Vision Research v310

- Two cameras per tower, level E,
- 1280x800 @ 3,200 fps, 8 GB, Color, HD-SDI Video Output to a HD recorder,
- Segmented memory, (12 @ 140 ms)
- 50% pre-trigger,
- Continuous recording,
- Restart after recording, FIFO,
- Triggered by the Genesis Transient Recorder, IRIG-B Synch
- 20-36 VDC, 70 W, Battery Backup Power with EMI filters and SPD
- Weatherproof enclosures with redundant AC units, and
- Stand alone temperature, humidity, power controller
- Dead-time of about 30 ms between segments (non deterministic)

High Speed Camera

Camp Blanding Tests

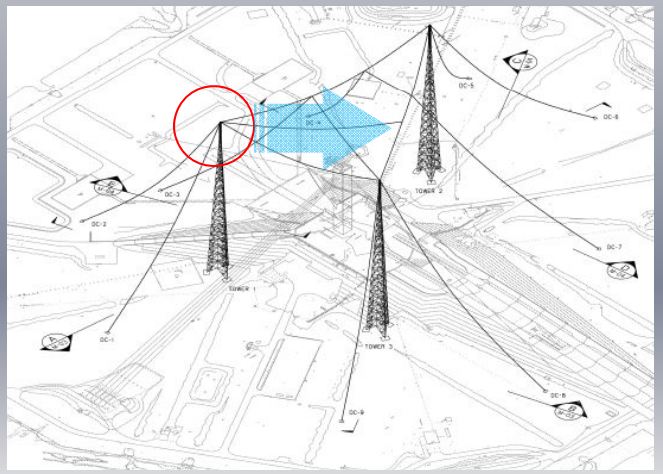
Camp Blanding Still Images

ICLRT – Camp Blanding
Rocket Triggered Lightning

High Speed Cameras

Tower 1 High Speed Cameras Field of View

Bottom Camera:
Tower 2

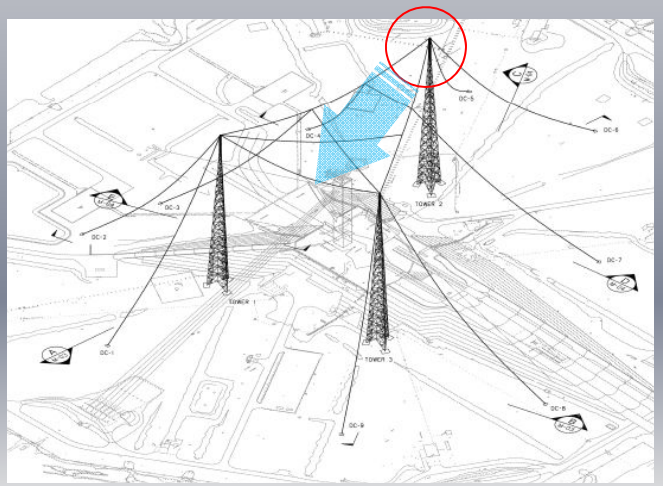


Top Camera:
Catenary (DC7) Pad A
background

High Speed Cameras

Tower 2 High Speed Cameras Field of View

Bottom Camera:
Tower 3 (VAB background)

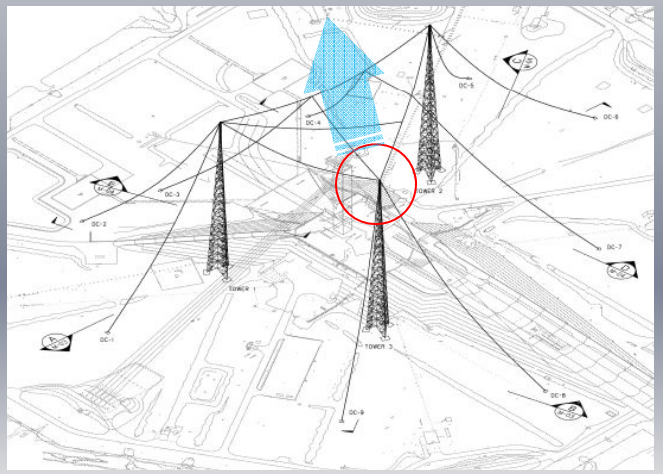


Top Camera:
Tower 1

High Speed Cameras

Tower 3 High Speed Cameras Field of View

Bottom Camera:
Catenary (DC3 & DC4)



Top Camera:
Tower 2

High Speed Camera

LCC High Speed Camera Field of View

How far can the high speed cameras see?

How far can the high speed cameras see?

How far can the high speed cameras see?

How far can the high speed cameras see?

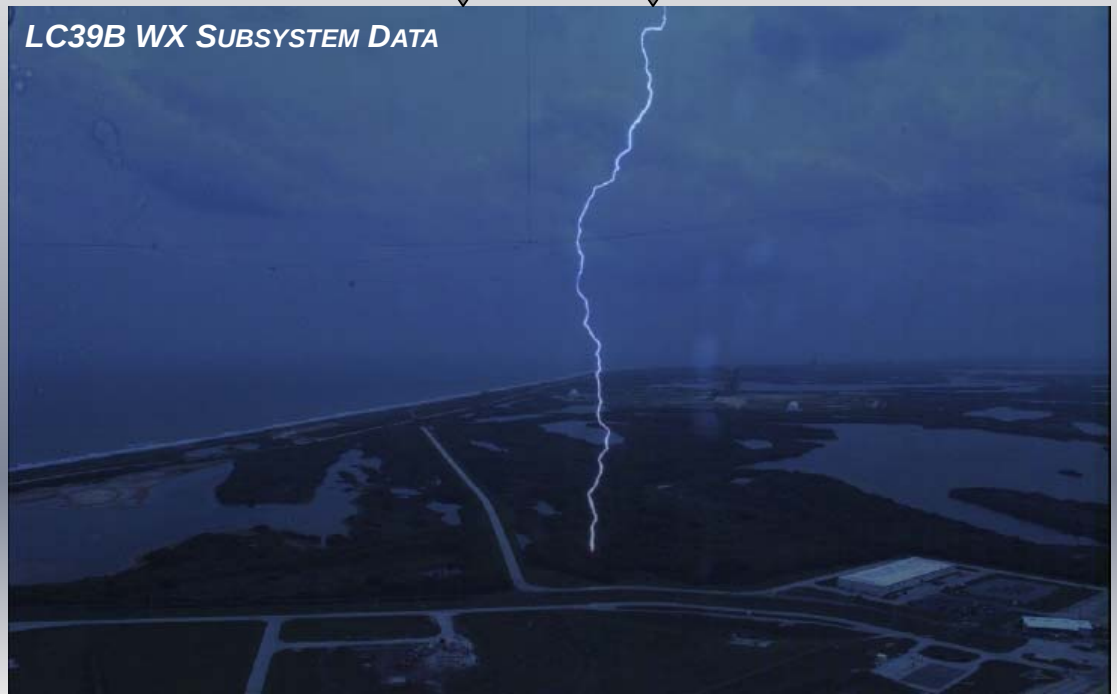
How far can the high speed cameras see?

How far can the high speed cameras see?

How far can the high speed cameras see?


LC39B WX SUBSYSTEM DATA

How can we determine the strike location (1)?



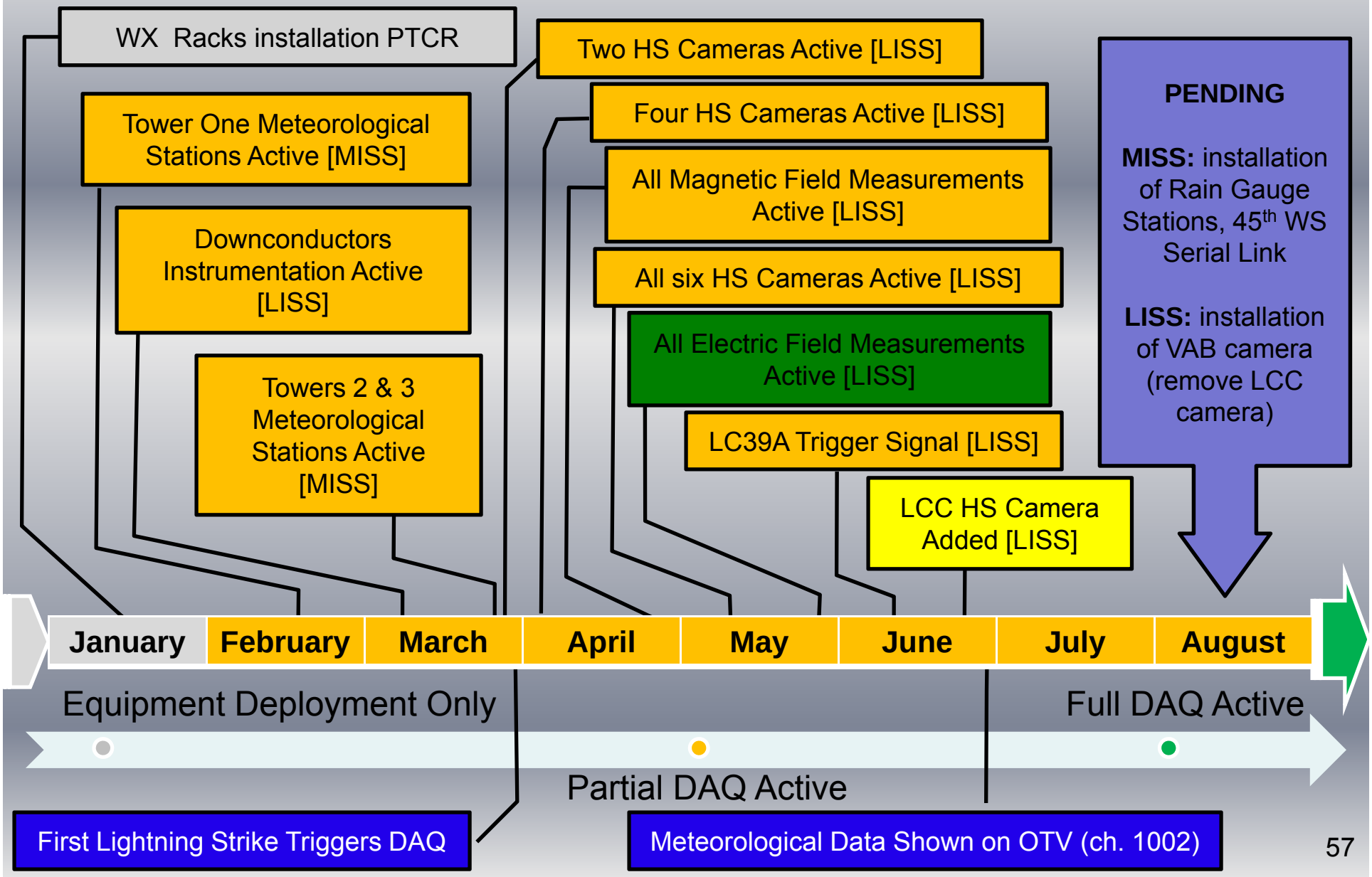
How can we determine the strike location (2)?

How can we determine the strike location (2)?

How can we determine the strike location (2)?

How can we determine the strike location (2)?

WX Subsystem LC39B Deployment, 2011



Direct Lightning Strikes LPS Pad B

RS #	Date (2011)	WX Subsystem					CGLSS		
		Time (UTC)	Delta T [ms] (sub. RS)	Strike Location	Ipeak [kA] $\sum I_{DC}$	Rise Time [us] (10%-90%)	Detected	# of sensors	Ipeak [kA]
1	3/31	14:50:49.887798	--	DC4	-28.8	2	No	--	--
2*	3/31	14:50:49.887798	180.445	Catenary (DC3)	-19.3	1.5	No	--	--
1	5/27	18:21:34.107026	--	Tower 2	-77.6	5.89	Yes	5	-57.0
1*	5/27	18:24:24.541573	--	DC8	-29.8	2.91	Yes	3	-18.2
1	5/27	18:25:47.633965	--	Tower 2 & nearby	-26.4	4.37	No	--	--
1	6/15	00:20:55.637149	--	DC8	-29.4	2.46	No	--	--
1	7/07	16:29:45.843432	--	Tower 3	> -174.3	5.41	Yes	5	-141.5
1	7/07	16:29:45.931982	--	Tower 2 & nearby	-74.9	5.66	No	--	--

* No video available for this event.

Two downconductor currents show saturation.

Direct Lightning Strikes LPS Pad B

RS #	Date (2011)	WX Subsystem					CGLSS		
		Time (UTC)	Delta T [ms] (sub. RS)	Strike Location	Ipeak [kA] $\sum I_{DC}$	Rise Time [us] (10%-90%)	Detected	# of sensors	Ipeak [kA]
1	7/07	16:35:59.648752	--	Tower 2	-67.8	4.78	Yes	5	-40.0
2*	7/07	16:35:59.731152	82.2	Tower 1	-47.4	3.9	Yes	5	-26.3
3	7/07	16:35:59.773986	42.834	Tower 1	-37.4	1.46	Yes	5	-16.8
4	7/07	16:35:59.796866	22.88	Tower 1	-18.5	1.09	Yes	3	-10.4
5	7/07	16:35:59.946027	149.161	Tower 1	-38.1	1.16	Yes	5	-23.1
6	7/07	16:35:59.992795	46.768	Tower 1	-27.4	1.13	Yes	5	-16.6
7	7/07	16:36:00.079704	86.909	Tower 1	-32.4	1.11	Yes	5	-19.7
8	7/07	16:36:00.145245	65.541	Tower 1	-17.6	1.08	No	--	--
1	8/14	21:10:15.787065	--	Tower 1	-64.1	6.06	Yes	4	-34.1
2	8/14	21:10:15.849042	61.977	Tower 1	-17.1	1.4	No		--
3	8/14	21:10:15.941681	92.639	Tower 1	-24.1	1.07	Yes	2	-14.2

LC39B Lightning Flashes Summary 2011

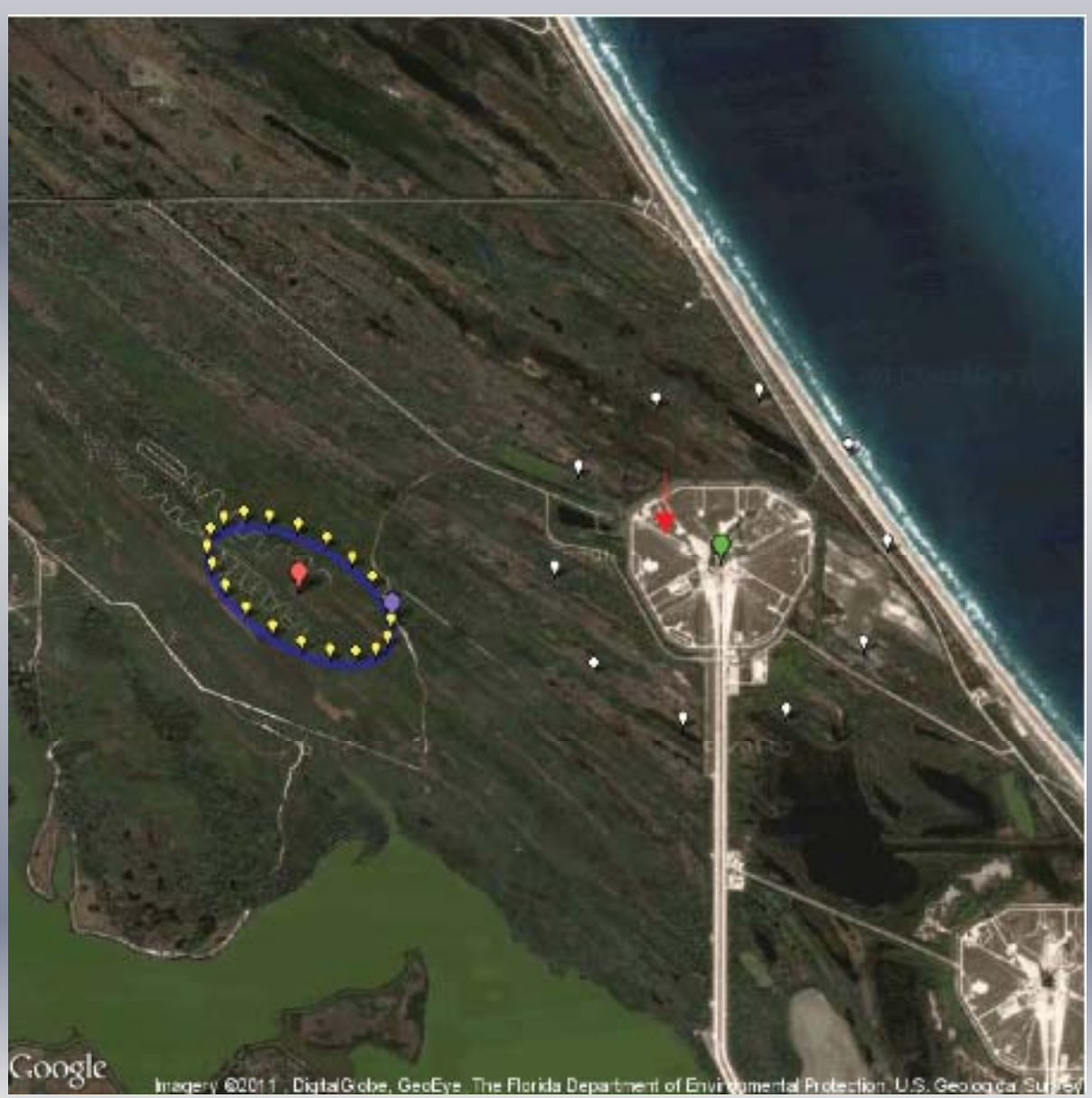
Between March and August:

- The Lightning DAQ has triggered on 11 different days.
- The lightning protection system has been struck directly by 9 lightning flashes (all towers are been struck):
  - 6 direct strikes to the towers
  - 3 direct strikes to catenary wires or downconductors
  - 6 single stroke flashes
  - 3 multi-stroke flashes (max. 8RS; min. 2RS)
- There have been 3 nearby lightning strikes within the LC39B perimeter:
  - 1 strike to the perimeter fence (multi-stroke flash)
  - 2 inside the perimeter (single-stroke flashes)
- How does the LC39B Lightning Instrumentation System compares to CGLSS II? ≈63%

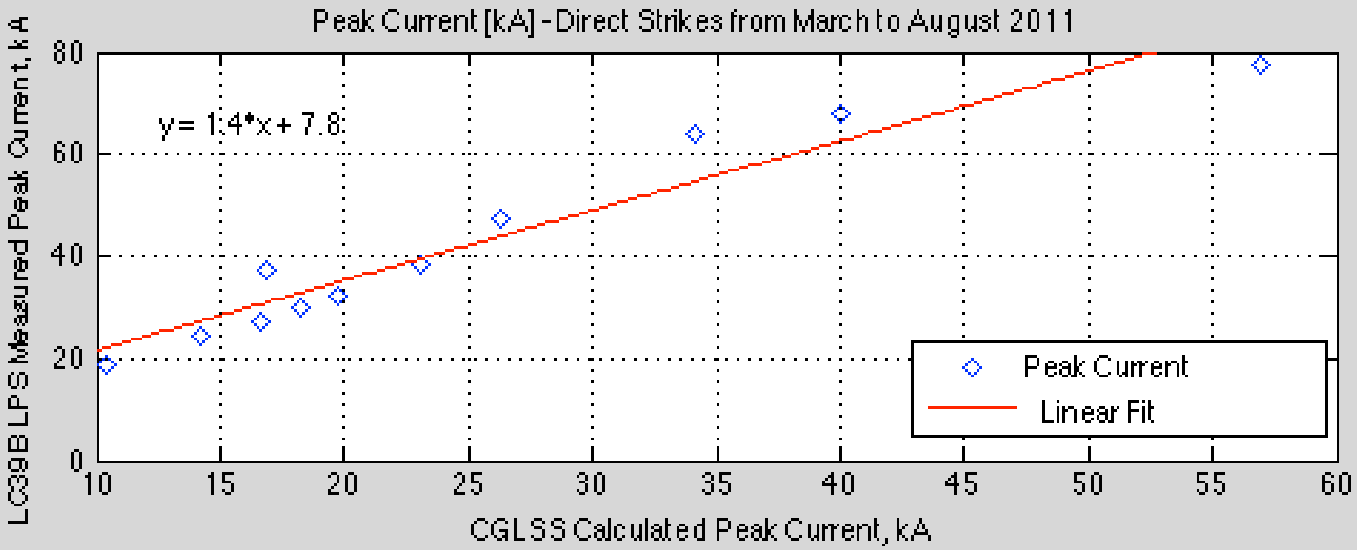
Lightning Instrumentation and CGLSS

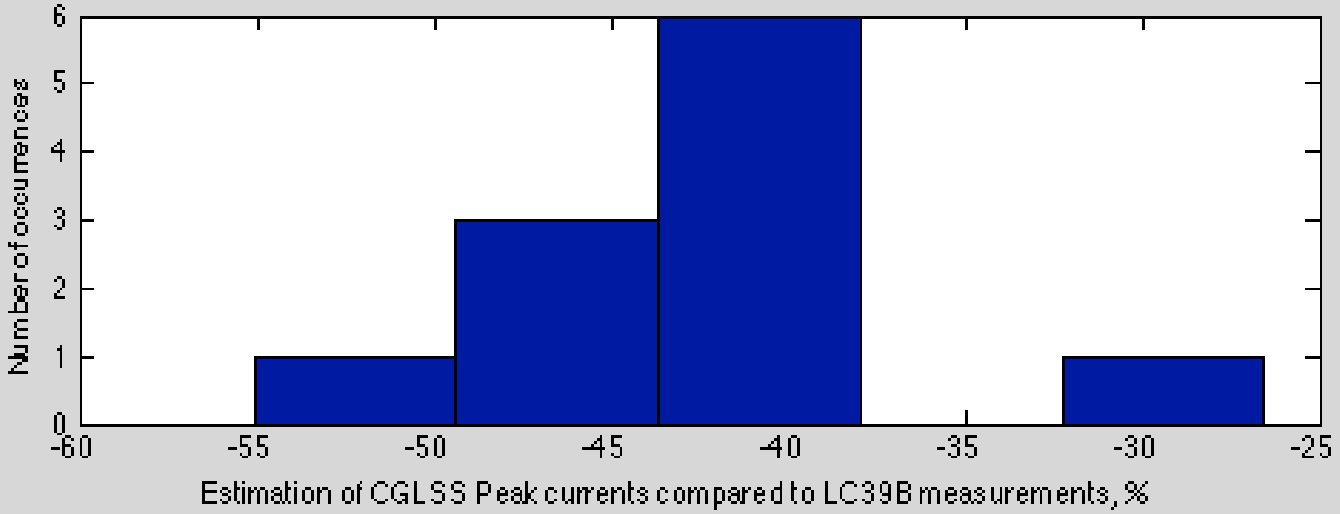
Lightning Instrumentation and CGLSS

Lightning Instrumentation and CGLSS



Lightning Instrumentation and CGLSS



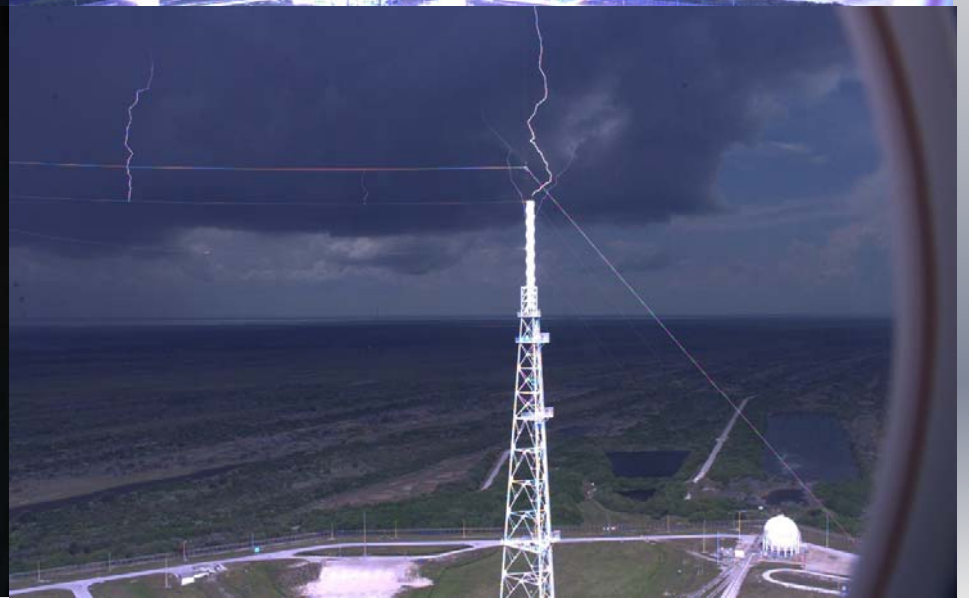


Selected Images

Direct Strike to Tower 2, 05/27/2011 18:21:34.107026 UTC.

Frame before 1st RS

Following frame



High Speed Video Camera Frames

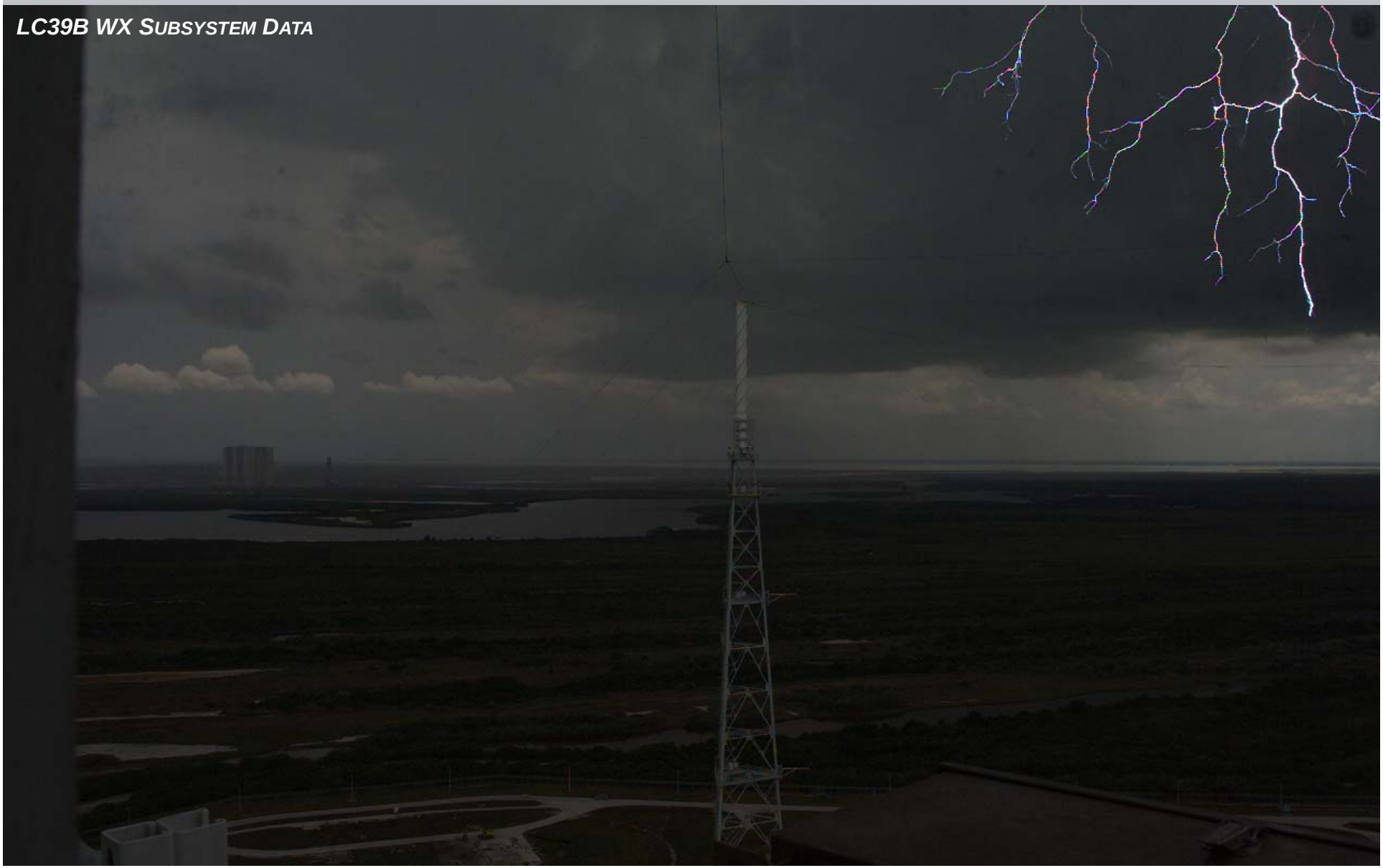
May 27 2011, 18:19:26.839007 UTC

High Speed Video Camera Frames

May 27 2011, 18:19:26.839007 UTC

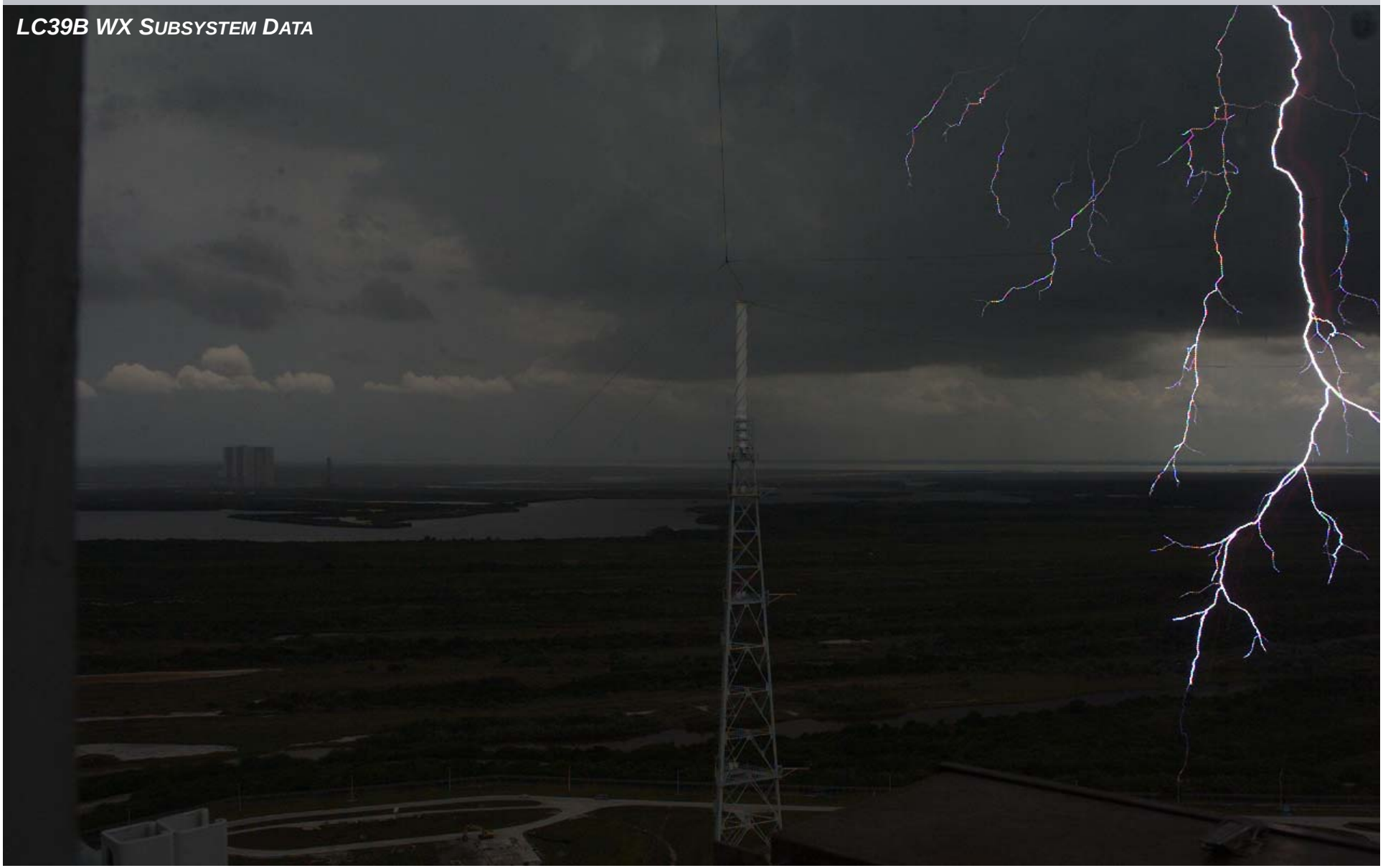
High Speed Video Camera Frames

May 27 2011, 18:19:26.839007 UTC



High Speed Video Camera Frames

May 27 2011, 18:19:26.839007 UTC

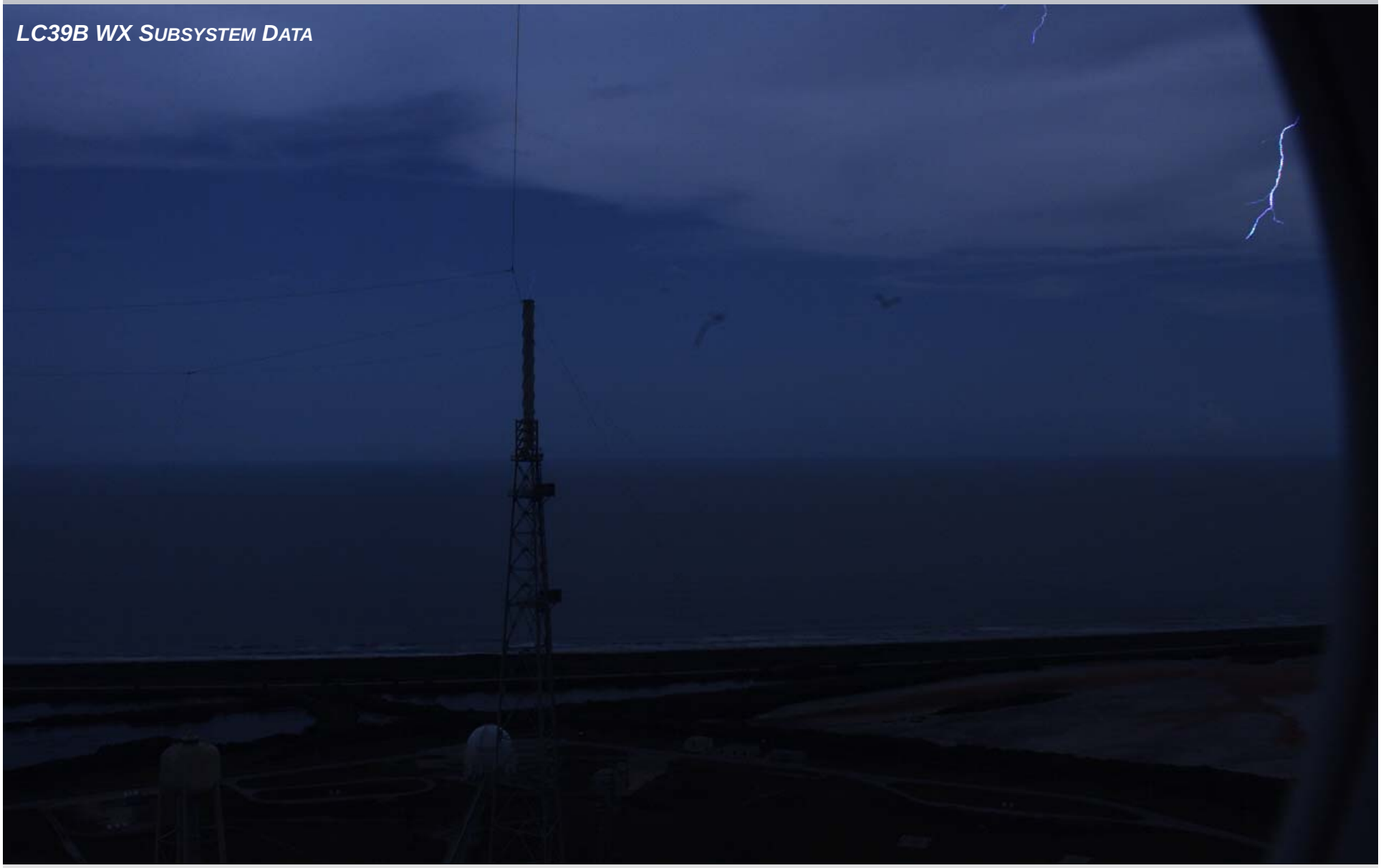


High Speed Video Camera Frames

May 27 2011, 18:19:26.839007 UTC

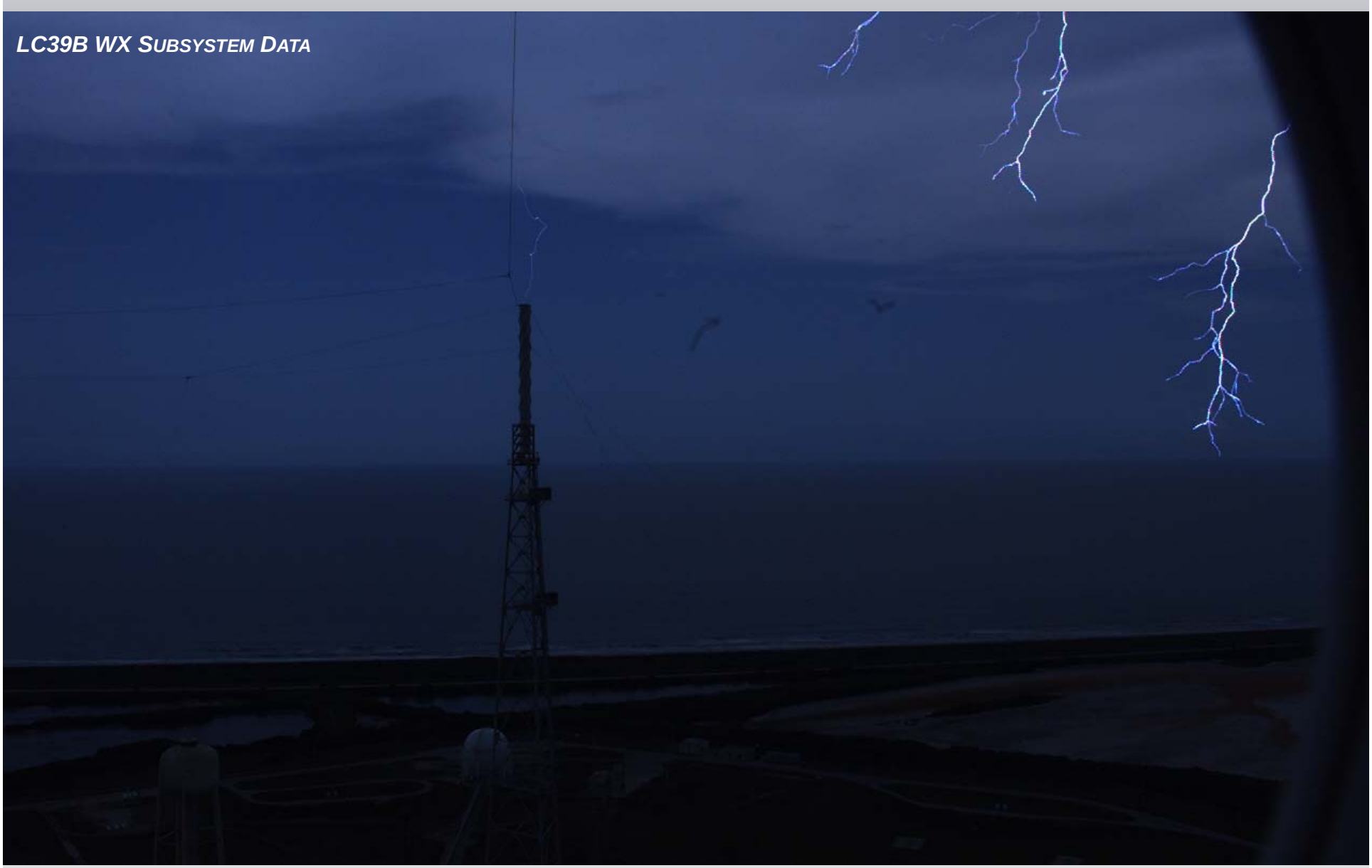
High Speed Video Camera Frames

May 27 2011, 18:25:47.634489 UTC



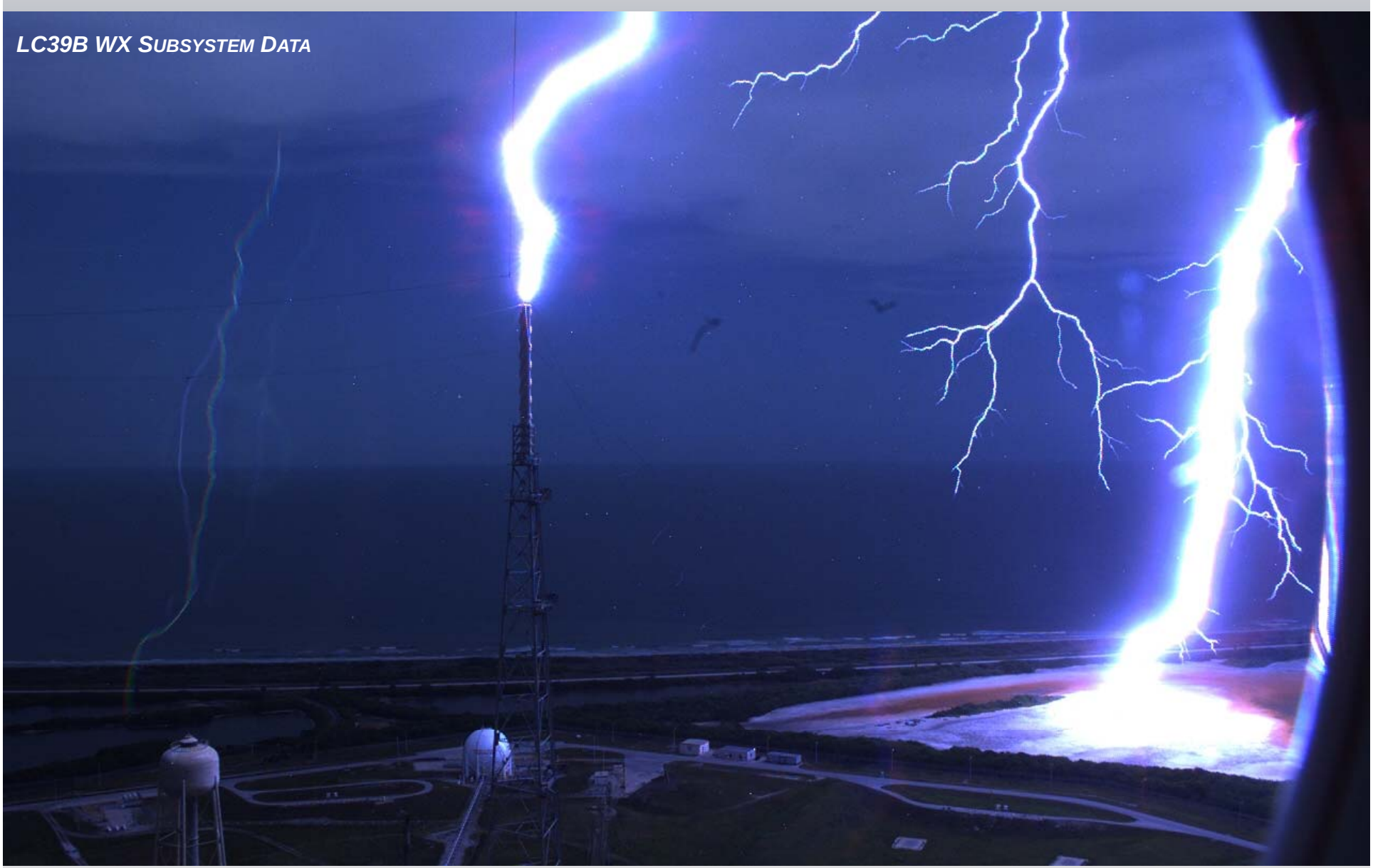
High Speed Video Camera Frames

May 27 2011, 18:25:47.634489 UTC



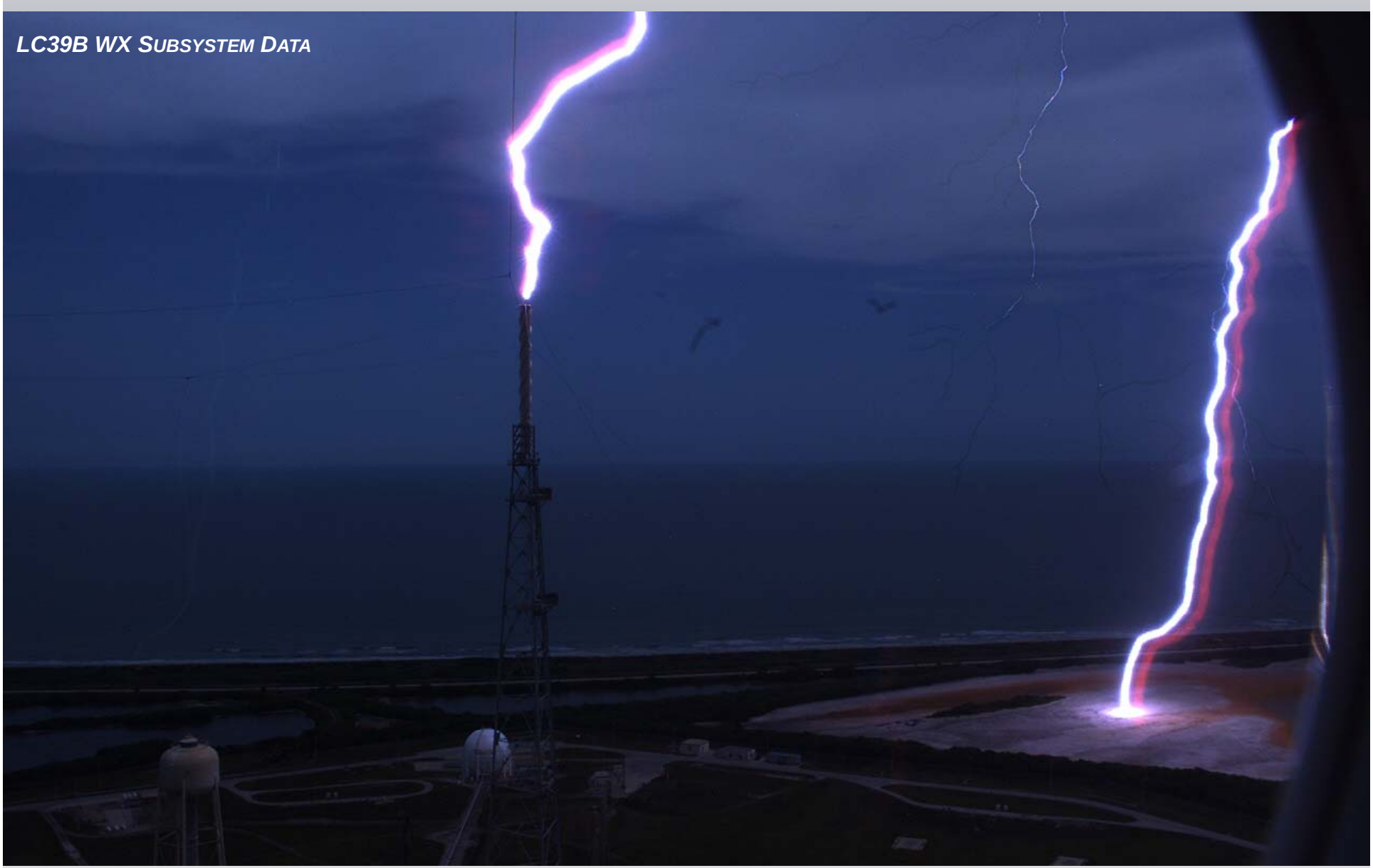
High Speed Video Camera Frames

May 27 2011, 18:25:47.634489 UTC



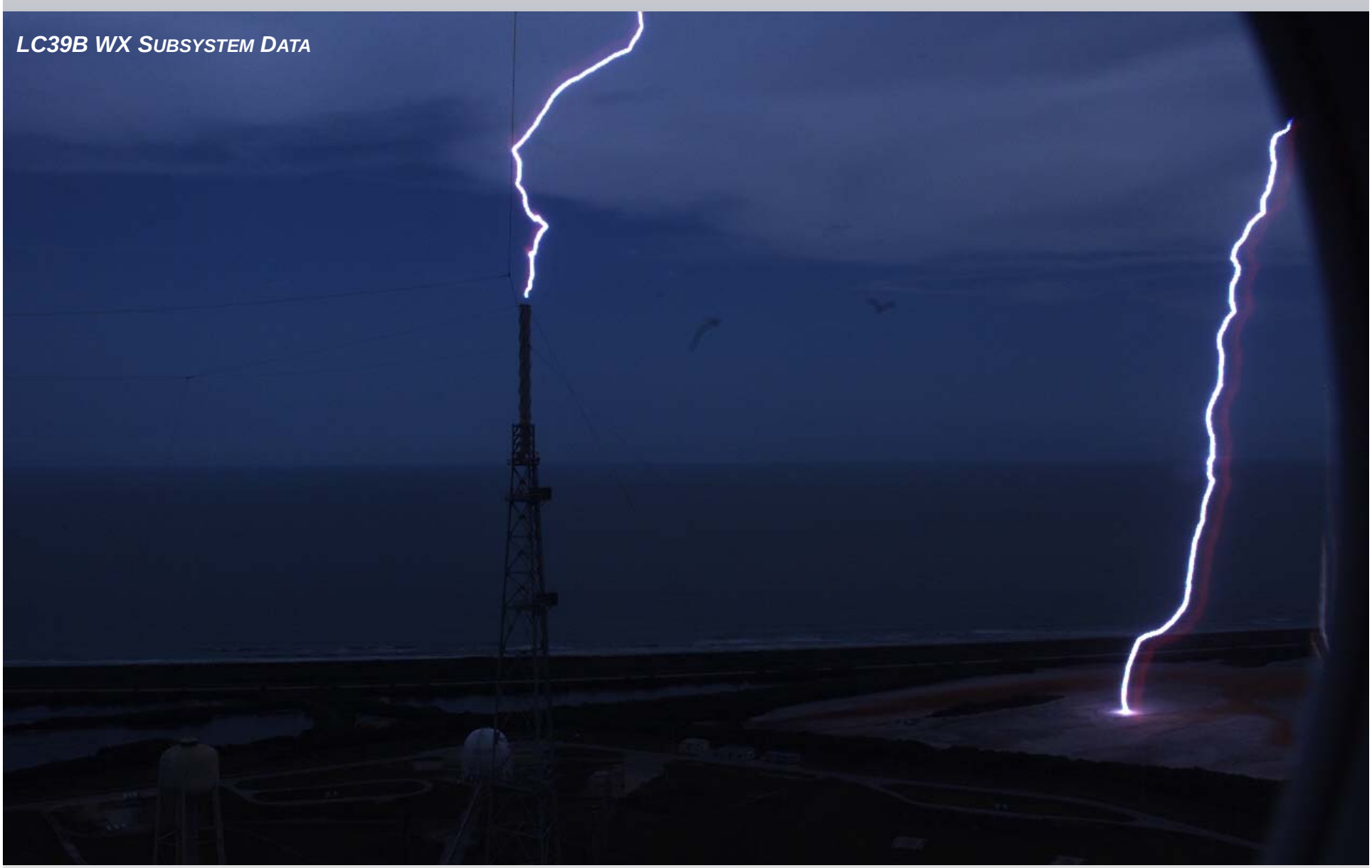
High Speed Video Camera Frames

May 27 2011, 18:25:47.634489 UTC



High Speed Video Camera Frames

May 27 2011, 18:25:47.634489 UTC

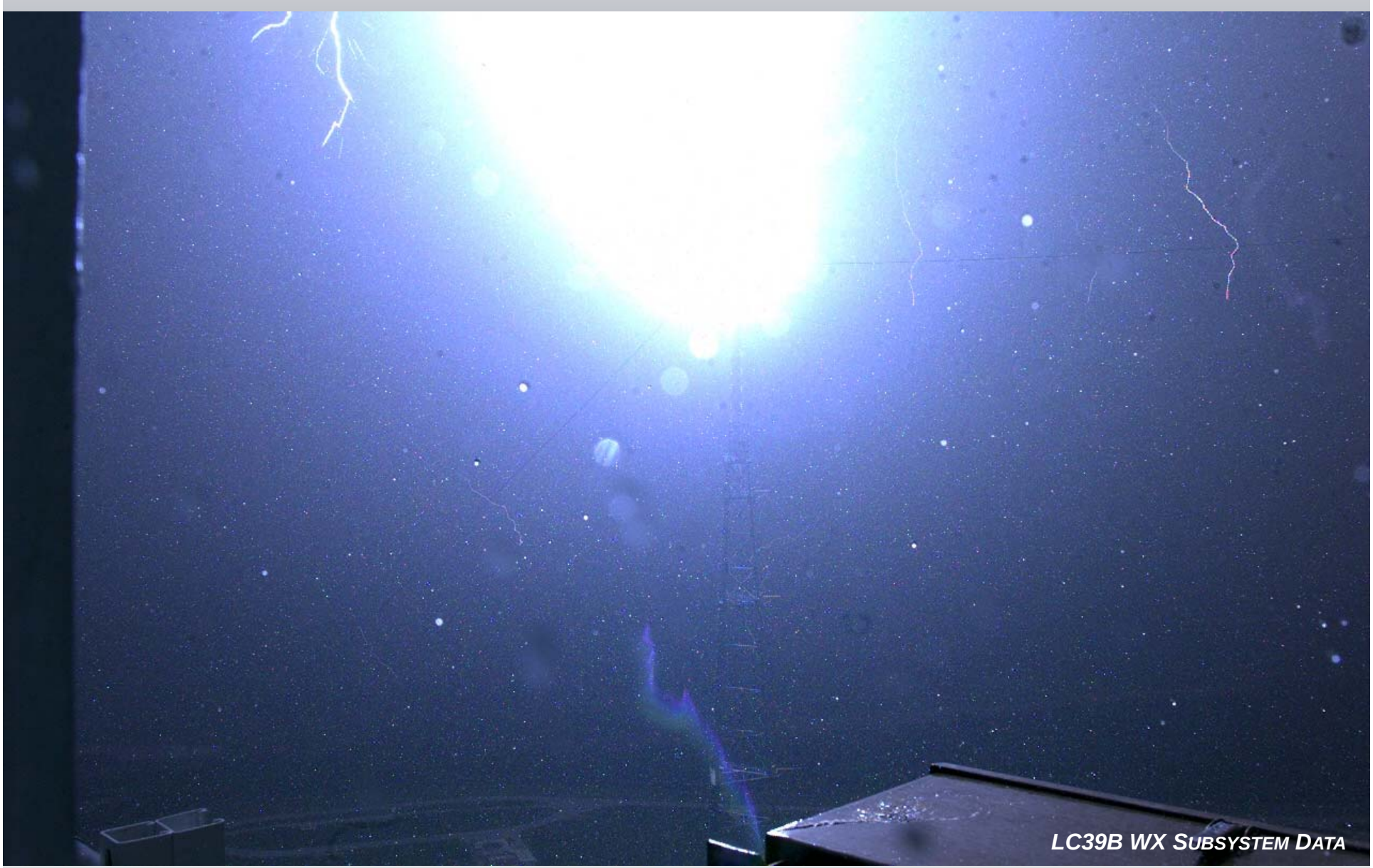


High Speed Video Camera Frames

July 07 2011, 16:29:45.844060 UTC

High Speed Video Camera Frames

July 07 2011, 16:29:45.844060 UTC



High Speed Video Camera Frames

July 07 2011, 16:29:45.844060 UTC

High Speed Video Camera Frames

July 07 2011, 16:29:45.844060 UTC

Selected High Speed Camera Images

Selected High Speed Camera Images

Selected High Speed Camera Images

Selected High Speed Camera Images

Selected High Speed Camera Images

Selected High Speed Camera Images

Advantages of the LC39B Lightning Instrumentation System

- Very high detection efficiency, perhaps 100%,
- Very accurate system,
- Direct measurements, Ip and dI/dt,
- System will allow us to improve lightning protection systems by providing data to refine the striking distance method,
- System will provide ground-truth data to improve lightning detection system peak current estimation,
- Save significant amount of man hours in the future,

THANKS!!!