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A LIGHTNING GRAND CHALLENGE: SANDIA'S 5 YEAR PLAN

(FY26-30)

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Sandia National Labs

U.S. DEPARTMENT OF ENERGY | NNSA

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WHAT QUESTION(S) ARE WE TRYING TO ANSWER

What did we see, how did we see it, and how variable is that observation?

- **BLUF: What is the complete population of all lightning processes and signals we can observe?**
- Answering this is fundamental to Sandia's mission. We can answer this question with directed, detailed analysis:
  - **Coincident Synthesis** (What happened at this time, in this location, based on these reports?)
  - **Time Series Behavior** (How did that signal evolve? What process or environment preceded/followed it?)
  - **Spatial Optical Scattering** (How did the environment change the source signal in space and time?)
  - **Spectral Analysis** (What is the temporal variability in spectra during a flash? How do sources of continuum emissions differ than sources of line emissions?)
  - **Cross-Phenomenology Comparisons** (How are the measurements of multiple phenomenologies [e.g. RF and optical] related to each other in time, space, and magnitude?)

OVERVIEW

Global Theme: Capturing The Population of Lightning Processes and Signals

- **Why**
  - Distinguish lightning from other sources for our deployed and future sensors
- **How**
  - **Models** – Build physics-based insight into the processes that create and determine the characteristics of lightning signals
  - **Measurements** – Leverage public data and community resources to verify and constrain models
  - **Analysis** – Understand the defining features and variability of lightning signals
- **What**
  - Capture and study the spectral, temporal, and spatial population of source signals to inform future instruments and algorithms
  - Understand the variety of heterogeneous cloud structures regionally, seasonally, and internally and how they complicate lightning signals
  - Leverage larger weather and lightning community expertise and sustain and continue engagement with community for years to come

DIVING DEEPER: WHAT?

What: Lightning as a signal and the environment that modifies it

- Capture and study the spectral, temporal, and spatial population of source signals to inform future instruments and algorithms
- Understand the variety of heterogeneous cloud structures regionally, seasonally, and internally and how they complicate lightning signals
- Leverage larger weather and lightning community expertise and sustain and continue engagement with community for years to come
  - Collaboration with universities (TTU/NMT), engagement with other agencies (NOAA/NASA) and contractors (Lockheed Martin).
- Sustain and continue engagement with community for years to come
  - Regular attendance at workshops and conferences (AGU, GLM Science Meeting, Modeling Workshop)
  - Continued collaboration with universities (TTU, NMT, etc.)

Acronyms:
TTU: Texas Tech University
NMT: New Mexico Tech
AGU: American Geophysical Union
GLM: Geostationary Lightning Mapper

DIVING DEEPER: HOW?

How: Three related thrusts, utilizing Sandia's expertise and relationships

Models

- Build physics-based insight into the processes that create and determine characteristics of lightning signals

Measurements

- Leverage public data and community resources to verify and constrain models

Analysis

- Learn how to distinguish lightning from other sources with confidence and traceability

THE LARGER LIGHTNING COMMUNITY

Lightning Modeling Grand Challenge Roadmap: Greater Community Effort

Models

- Clouds
- Radio Frequency Source
- Streamer-Leader
- Radio Frequency Propagation
- Lightning Initiation
- Optical Signal Source
- Lightning Discharge
- Optical Signal Propagation
- Electromagnetic Field Change
- Other Phenomenology
- Ancillary Observables
- Model Stitching

Measurements

- Electromagnetic Field Change
- Optical Spectral
- Radio Frequency
- Optical Broadband
- Radio Frequency Propagation
- Optical Signal Propagation
- Ancillary Observables
- Ground Deployments
- Low Rigor Rapid Deployments
- Airborne Deployments
- High Rigor Deployments
- Space Deployments

Analysis

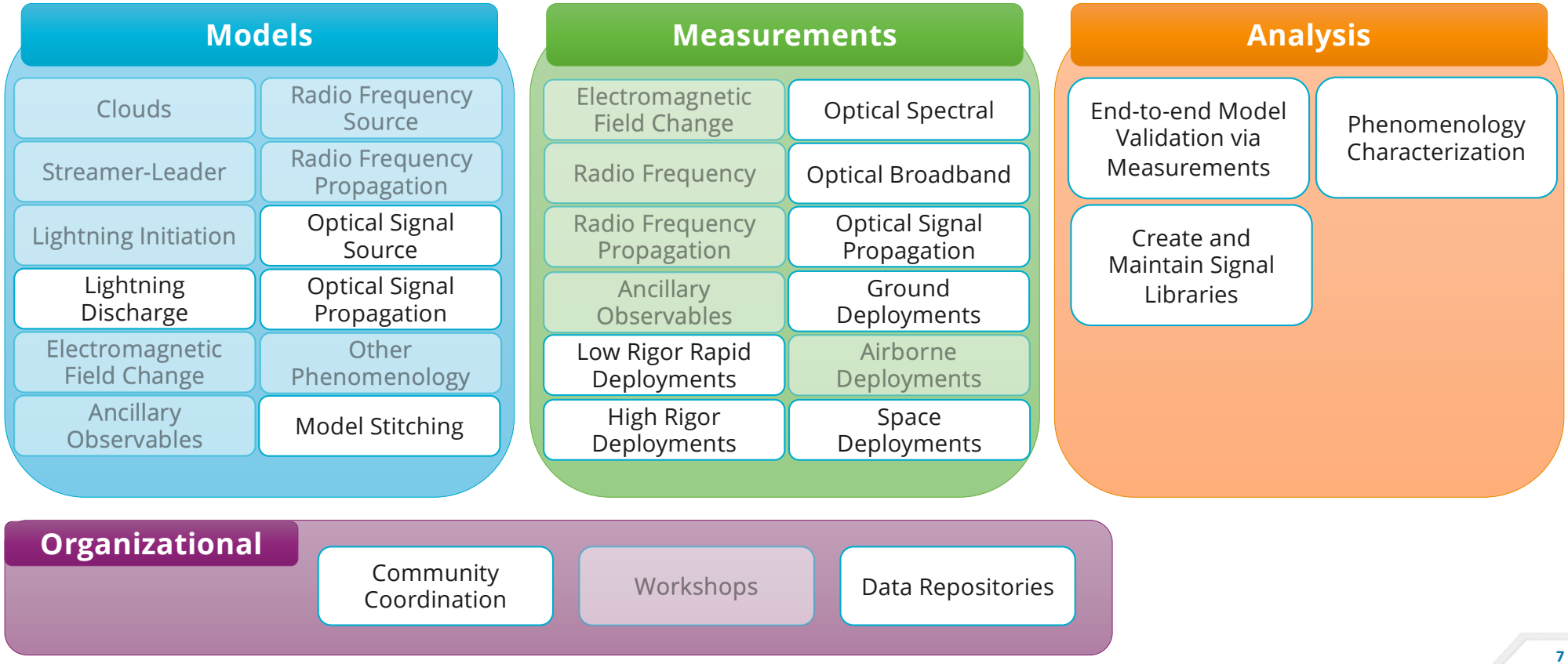
- End-to-end Model Validation via Measurements
- Phenomenology Characterization
- Create and Maintain Signal Libraries

Organizational

- Community Coordination
- Workshops
- Data Repositories

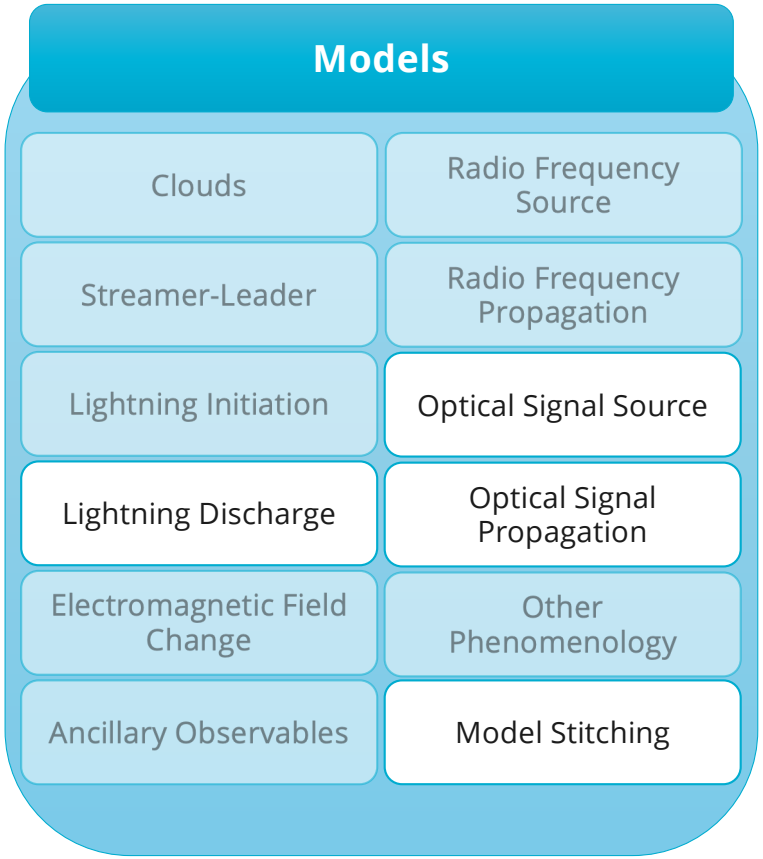
SANDIA'S INVOLVEMENT

Lightning Modeling Grand Challenge Roadmap: Sandia's Focus



MODELS – OVERVIEW

- Sandia has multiple efforts, both in progress and planned for the future:
  - FLASH – Electro-hydrodynamic model of the lightning return stroke
  - Caitano Model – Phenomenological model of lightning return stroke
  - Spark LDRD – Experimental validation of lightning spectra model
  - Optical Transport – Temporal, spectral, spatial characteristics modified by atmospheric transport
  - Model Stitching/Interface – demonstrate how to develop interfaces



MODELS – NEEDS, OUTLOOK, AND TIMELINE

Acronyms:
WRF: Weather Research & Forecasting Model

Needs and Outlook

- Sandia needs a better understanding of the models and outputs that are currently in development *outside* of Sandia.
  - Use of weather model outputs
  - Cloud structures and electrification (WRF/WRF-elec)
  - Branched discharge structure
  - Leader/Streamer processes
- Sandia is not developing these models, but needs awareness to fit together into the larger initiative.

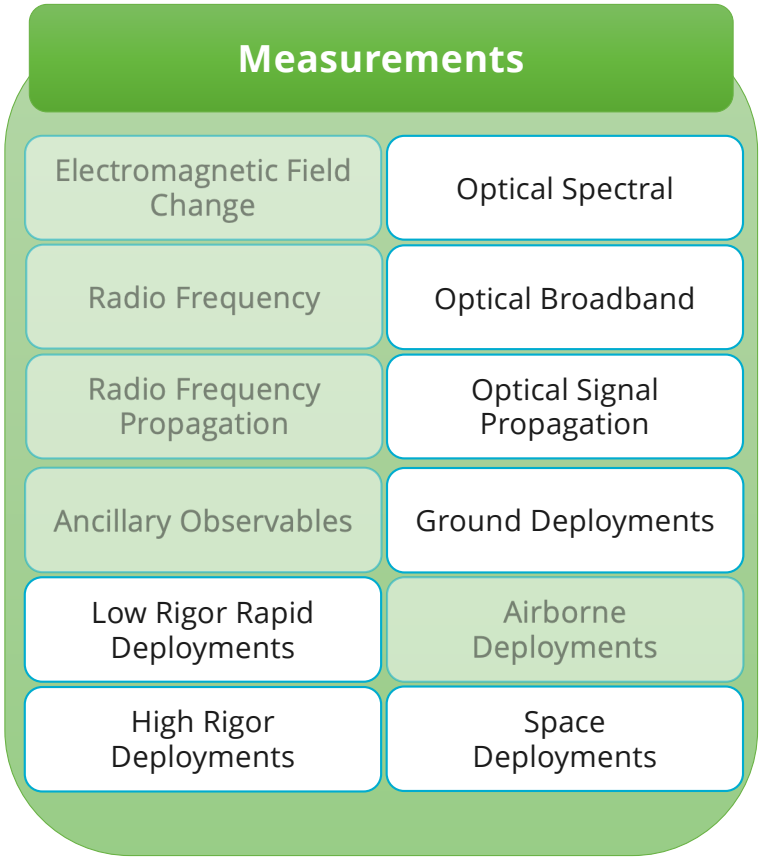
Timeline

- Short term: Stitch between Sandia's models and easily integrated outside sources
  - WRF-elec → FLASH
  - FLASH → Optical Transport
- Long term: Aim for the end-to-end capability
  - Lab measurements to compare against models
  - Use global weather models as inputs
  - Test against "Golden Days" (See Measurements section)
  - Design measurement instrumentation and deployments focused on model validation

MEASUREMENTS – OVERVIEW

Acronyms:
DrEvl : Dragon's Fly-Eye Viewing Lightning
LEO: Low Earth Orbit

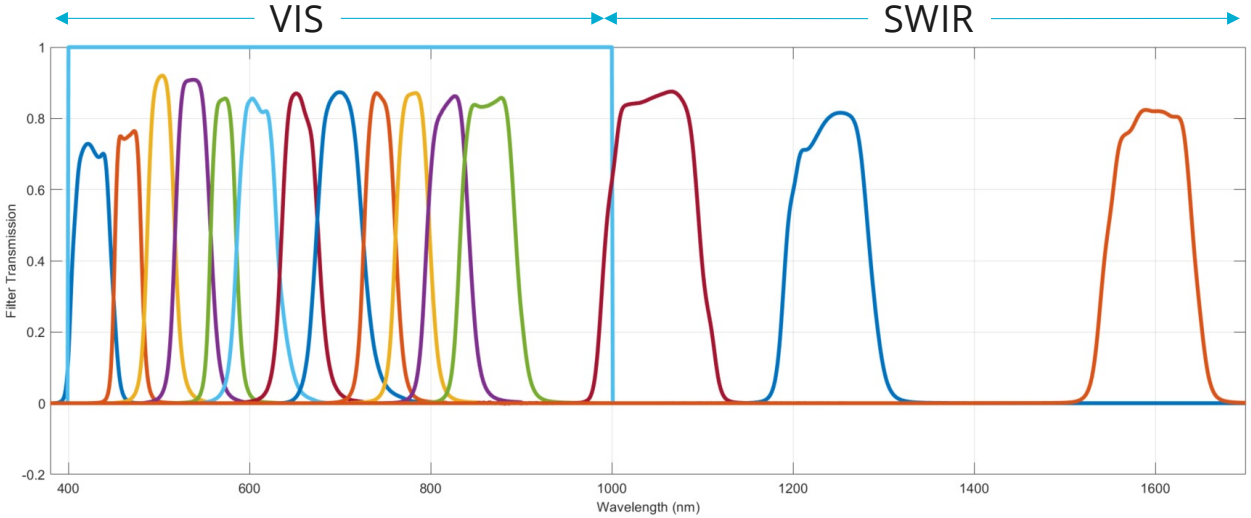
- Sandia focuses on optical instrumentation between 250 nm and 2 microns on a variety of platforms and deployments:
  - Lydia Radiometer - Pathfinding, multi-channel collection, first light co-collect w/ other sensors
  - DrEVL – High sample rate, mobile, multi-channel collection
  - Big Boy - Higher channel count radiometers, coupling high speed imaging with radiometers, opportunity to fly in LEO
  - Spectrometer - High spectral/temporal resolution for long data records, to distinguish unique characteristics of lightning (spectral/temporal)



BIG BOY LEO LIGHTNING PAYLOAD

Sensor	FOV	Pixel GSD	Sample Rate
VIS Radiometer	Circular, 31.6°, 227km	N/A	100KHz
SWIR Radiometer	Circular, 21°, 150km	N/A	100KHz
Luxima Camera	31.5°x31.5°, 225x225km	0.44km, 1.32km 3x3 binned	4KHz
EVK4 Camera	42.5°x24.7°, 311x175km	0.243km	~10KHz equivalent

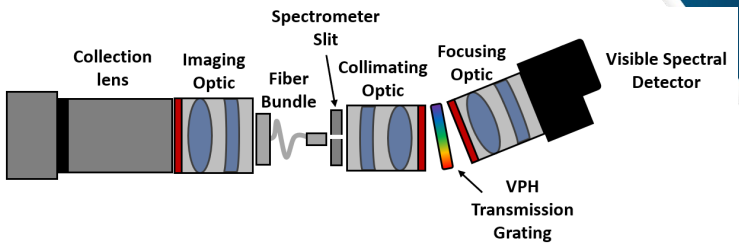
16 Custom Filter Radiometer Bands

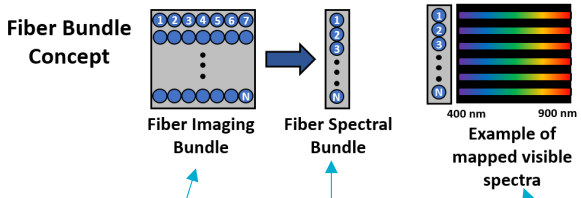


- 15 week mission on ISS
- Expect to capture ~12,000 flashes
- 1s post-triggered + 5ms pre-trigger buffered on all sensors
- ~15 months kickoff to delivery
- Launch expected late CY2025

SPATIAL/SPECTRAL/TEMPORAL LIGHTNING SPECTROMETER

- This concept is unique in that the fiber grid (planning 7x7) spatially samples the scene and does not rely on the lightning channel itself to serve as the slit.
- Prototype version is being assembled now (March 2025) using COTS lenses, a custom assembled fiber bundle, and a Phantom camera
- Hoping to collect lightning data in the field summer 2025
- Follow on version with custom optics and a blue-enhanced Phantom camera (need to purchase) is desired to extend the range down to 300nm in the blue.



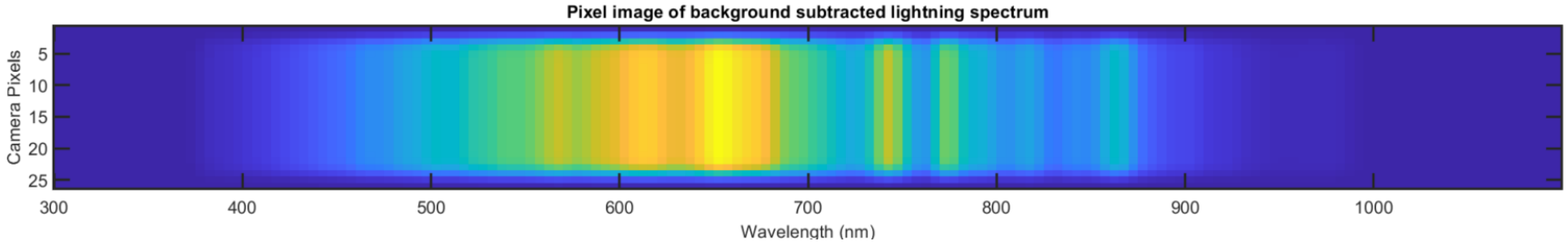


2D spatial image onto fiber bundle

Re-arranged into 1D stack in front of slit

Spread spectrally by grating onto 2D high speed camera

Simulated 5nm resolution spectra from single fiber



MEASUREMENTS – NEEDS, OUTLOOK, AND TIMELINE

Needs and Outlook

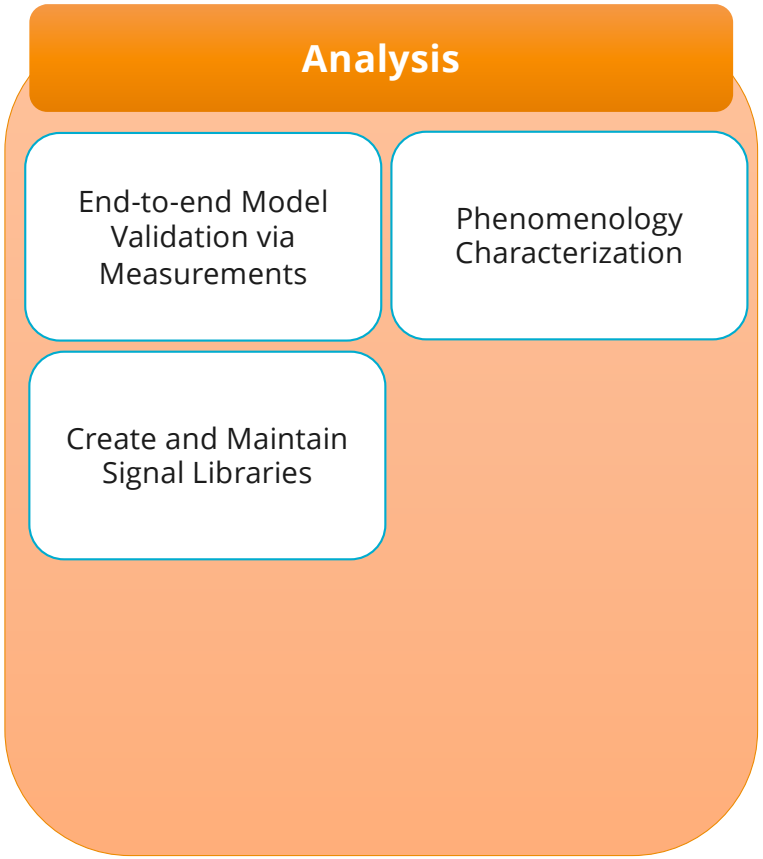
- Many platforms/field deployments currently scoped.
  - TTU Field site and mobile operations: Highly instrumented, aiming at “Golden Day” observations (high number of deployed and working sensors + good storms)
  - High altitude and on-orbit pathways – ISS, ER-2, Balloons/Stratolite, C-130
- Instrumentation already deployed in multiple areas, with more instrumentation in development.
- Sandia will need outside cooperation to coordinate multi-sensor deployments.

Timeline

- Short term: Iteration on radiometry, extension to more deployment opportunities
  - Modification of current radiometers for mobile operation (Vans, tripod)
  - Iteration on radiometric instruments (DrEVL, BigBoy)
- Long term: Novel technology, coordinated deployments
  - Spectrometer – First on ground, then on airborne platforms
  - Second shot on ER-2, potential to incorporate new C-130 Hurricane Hunters

ANALYSIS – OVERVIEW

- Using the instrumentation from Sandia and the rest of the community, Sandia is focused on distinguishing lighting signals from other sources.
  - Coincidence Synthesis - measurement phenomenology cross comparisons, timing and strength of RF vs. optical
  - Time series behavior - time intensity signal characteristics, sample rate effects and/or characterization of high-speed continuing current
  - Spatial optical scattering - pixelated sensor looking at thick clouds, spatial size and temporal movement of optical signals
  - Spectral – temporal and spectral variability across flashes, separation of continuum from line



ANALYSIS – NEEDS, OUTLOOK, AND TIMELINE

Needs and Outlook

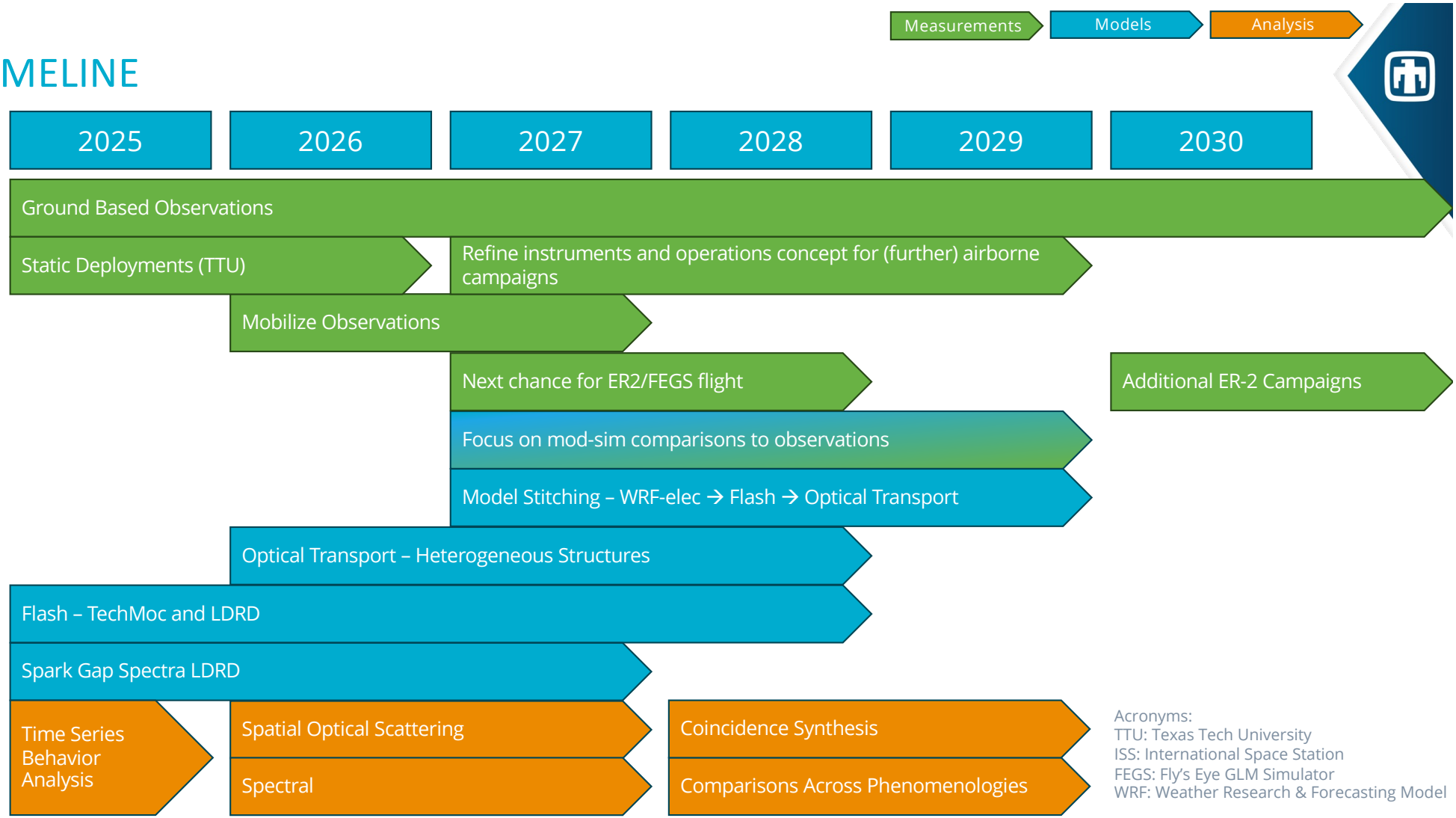
- Sandia aims to build signals libraries across many sensing modalities, focused on model validation cases and distinguishing characteristics of lightning from other sources.
- Already have experience with many datasets: FEGS/FEGS2, GLIMS, GLM/MTG-LI, WWLLN/NLDN/GLD360, Spectrometer, Ground Radiometry
- Cross-instrument analysis aims to validate models and develop methods to distinguish lightning from other sources.

Timeline

- Short term: Single instrument + Model integration
  - Time series behavior analysis
  - Spatial optical scattering
  - Spectral behavior in time and space
- Long term: Cross-sensor and cross-phenomenology synthesis
  - Coincidence across sensors
  - Comparisons of optical and RF phenomenologies

Acronyms:
FEGS: Fly's Eye GLM Simulator
GLIMS: Global Lightning and SprIte Measurement
GLM: Geostationary Lightning Mapper
MTG-LI: Meteosat Third Generation Lightning Imager
WWLLN: World Wide Lightning Location Network
NLDN: National Lightning Detection Network
GLD360: Global Lightning Detection Network

TIMELINE



Acronyms:
TTU: Texas Tech University
ISS: International Space Station
FEGS: Fly's Eye GLM Simulator
WRF: Weather Research & Forecasting Model