National Aeronautics and Space Administration

CubeSpark: A New 3D Lightning Observing Concept

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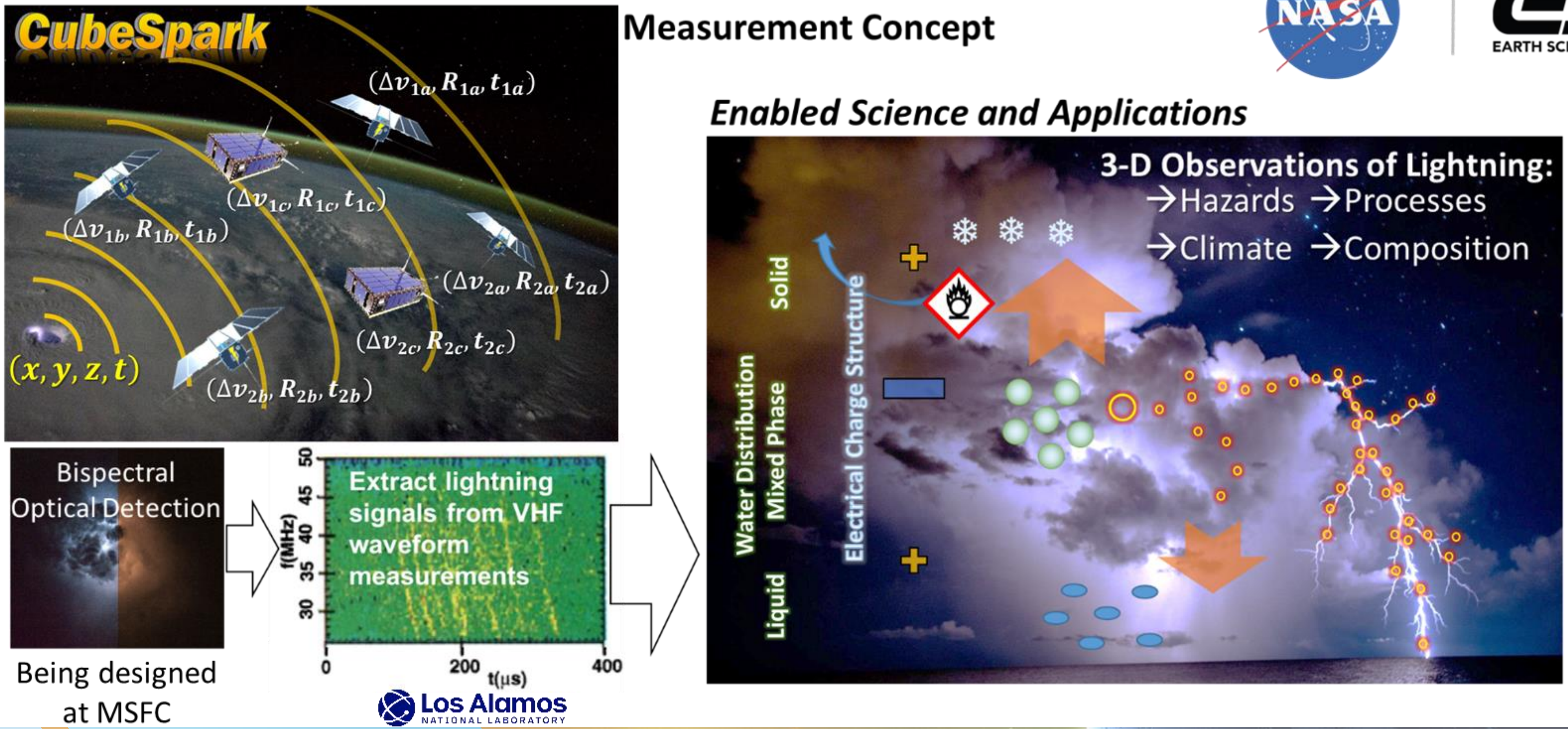
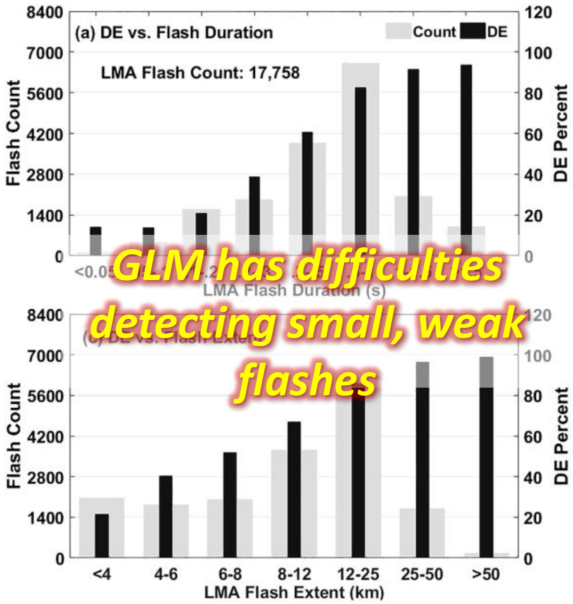
CubeSpark will expand 3-D observations globally

Constellation of small satellites acting as a 3D lightning mapping network in space:

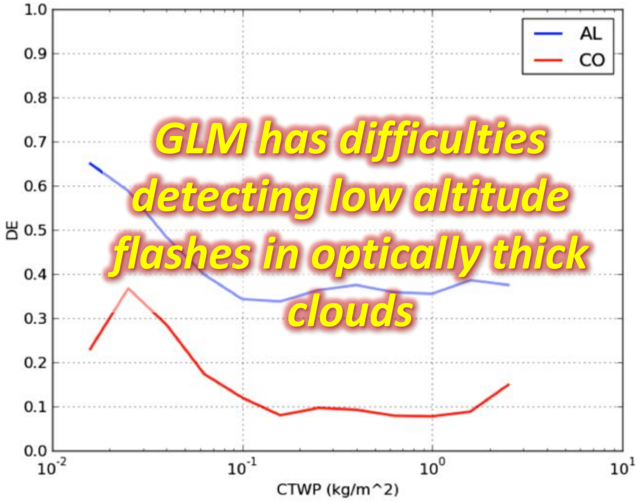
- *VHF radio measurements to map lightning structure inside clouds*
- *Bispectral, high-resolution optical measurements to enhance detection of lightning in severe and anomalous thunderstorms and flashes that extend upward from cloud-top*



Existing satellite-based lightning mappers give coarse 2-D view that often cannot depict important characteristics of thunderstorm intensification



Zhang and Cummins (2020)

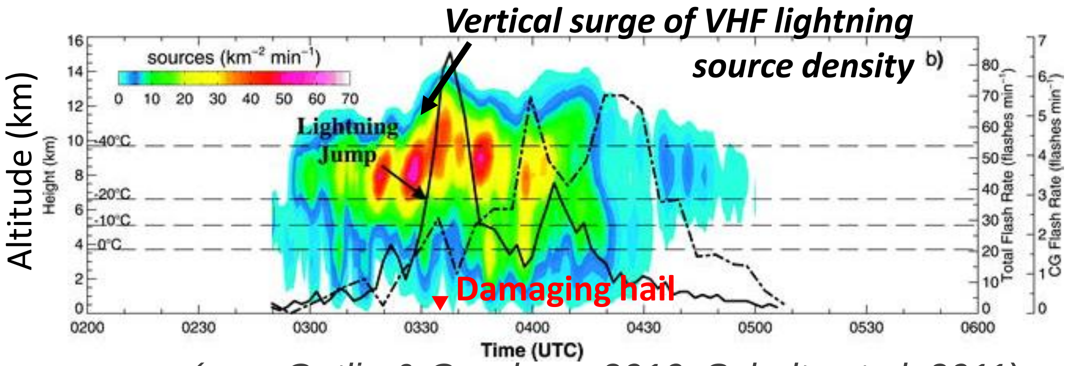


Rutledge et al. (2020)

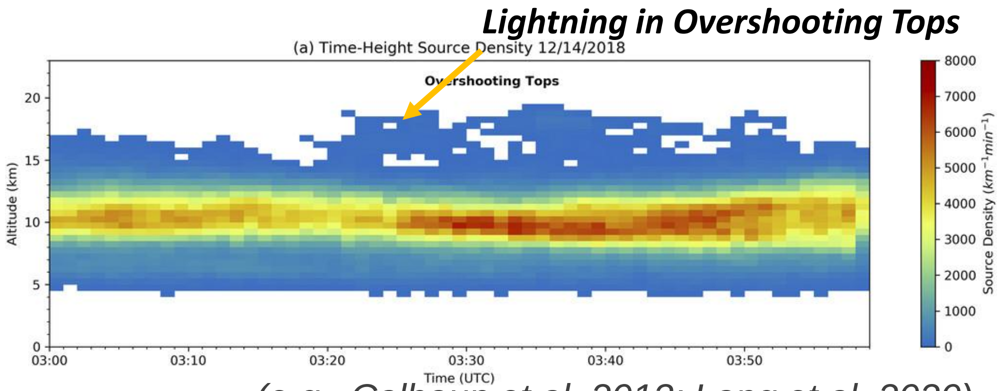
- *Difficult to fully understand the connection between storm intensity and lightning activity, which has implications for:*
  - *Forecasting severe weather*
  - *Depicting regional/seasonal variations of processes important to the water & energy cycle*
- *Unable to resolve thundercloud electrical charge structure on a global scale, which has implications for:*
  - *Identifying storms with potential for high impact CG flashes (e.g., those likely responsible for wildfires, power-outages, crop/property damage, etc.)*
  - *Depicting vertical distribution of LNOx and resultant effects on tropospheric ozone concentration*

Vertical observation is key to extracting vital information content from lightning

Storm Intensification and Severe Weather

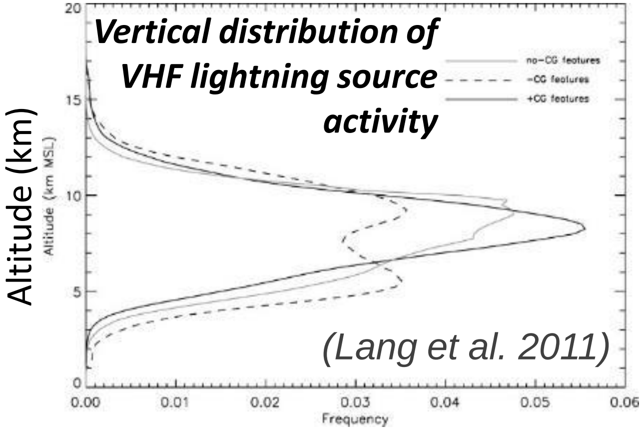


(e.g., Gatlin & Goodman 2010; Schultz et al. 2011)



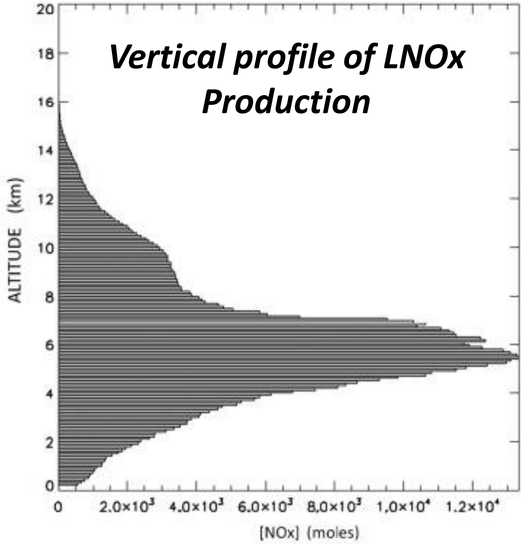
(e.g., Calhoun et al. 2013; Lang et al. 2020)

Anomalous Charge Storms and Flash Type/Polarity



(Lang et al. 2011)

Lightning-produced Nitrogen Oxides and Impact on Climate/Air Quality



(Koshak et al. 2014)

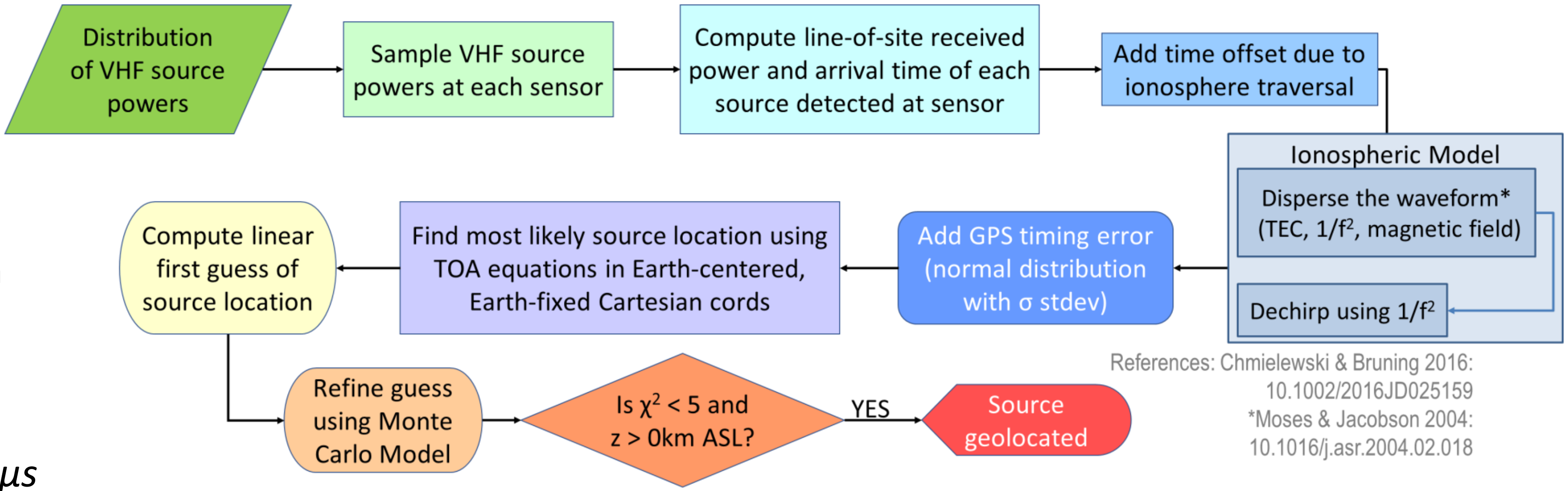
These studies enabled by 3D Observations of Lightning Activity have been <u>limited to regional networks</u>

Using an LMA-like approach in space to get *useful* 3-D observations of lightning

- FORTE and RFS studies tell us **lightning emissions at VHF escape the ionosphere**
- The main question is how accurate are the retrieved locations from a distributed network of VHF sensors in space? ≤ 2-km is needed to map charge regions; ≤ 1-km to map flash extents

Modified LMAsimulation software to investigate 3D location uncertainties from orbital network

**used GPS timing uncertainty~0.5-1 μs*

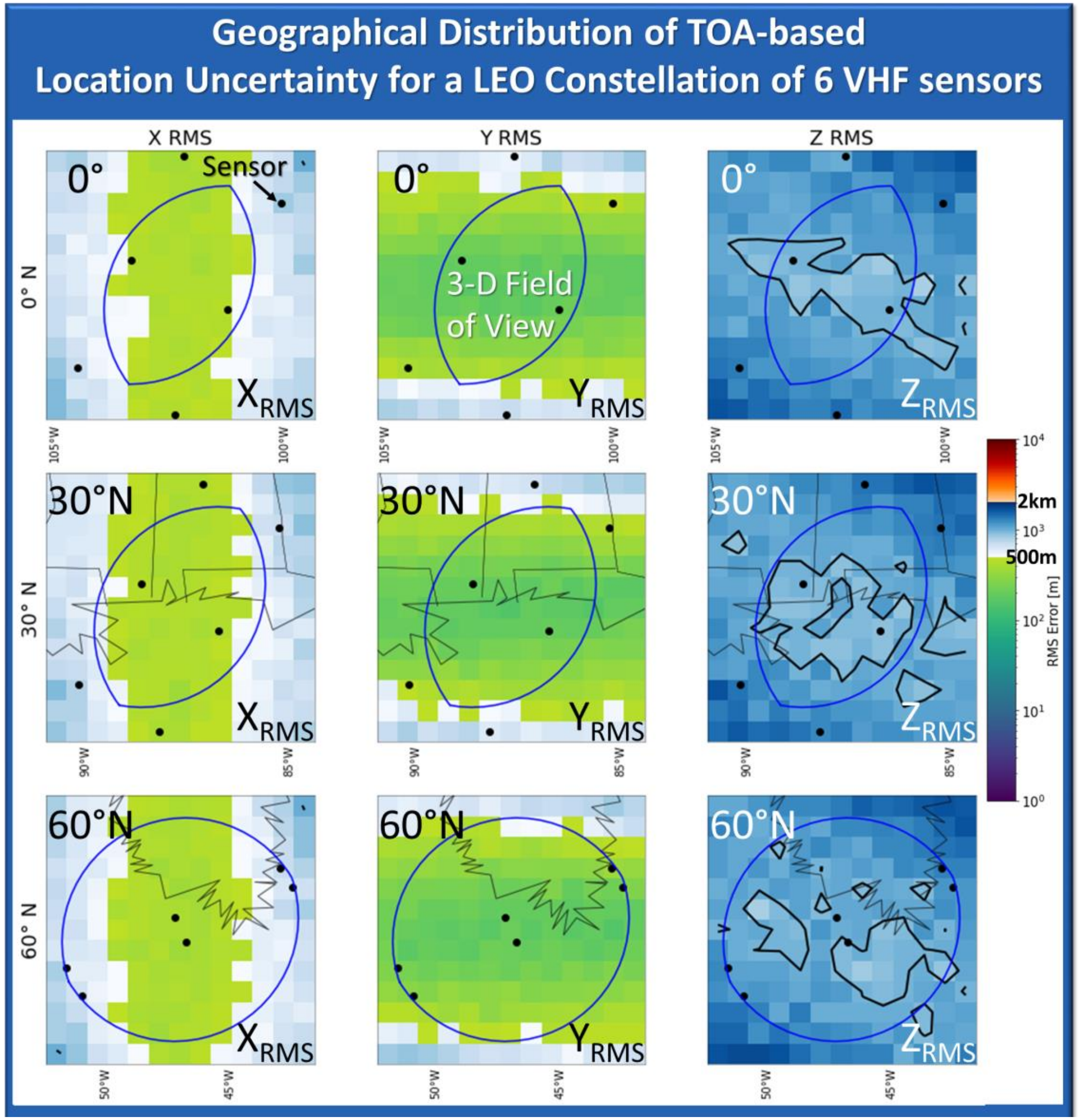


References: Chmielewski & Bruning 2016: 10.1002/2016JD025159
*Moses & Jacobson 2004: 10.1016/j.asr.2004.02.018

Results of Orbital LMAsimulations

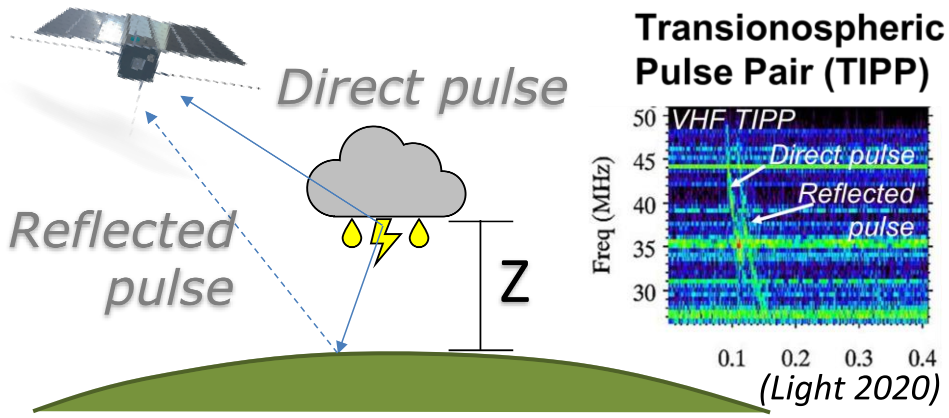
- Uncertainty added by ionosphere negligible for altitudes below 550-km
- RMS uncertainty in Z<2-km for sensor separation >350-km
- Constellation of 6-sensors an altitude of 550-km and separated by 350-km at an orbital inclination of ~63°

<u>Main Takeaway</u>: Retrieval of the 3D location of lightning with ≤ 1-2km uncertainty is possible over 300-600 km swaths from the tropics to the high latitudes



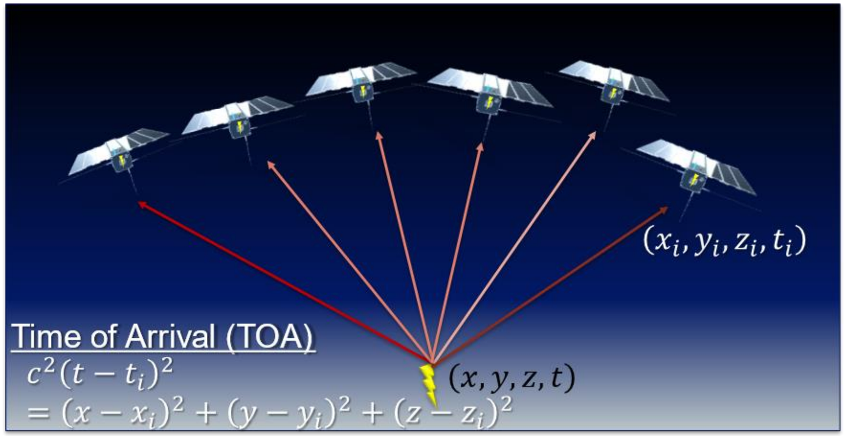
Approaches for spaceborne 3-D geolocation of lightning

Single satellite: TIPP+optical



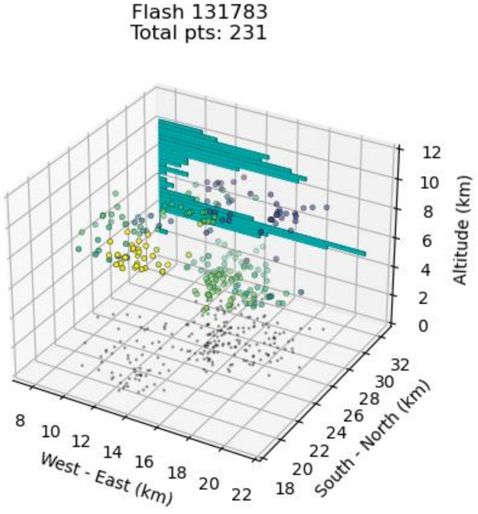
- RF gives altitude; Optical gives lat/lon
- 3D requires detection of reflected pulses (TIPP) coincident with optical
- Vertical RMS error ~ 300 m (σ_{timing}=0.5 μs)

Multi-satellite: Time-of-arrival (TOA)

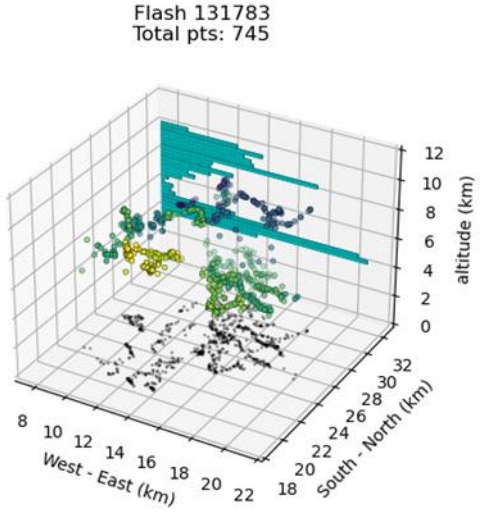


- Doesn't rely on reflected pulse for 3D
- Optical can be used to reduce number of VHF detections required for 3D retrieval
- Vertical RMS error ~ 1-2 km

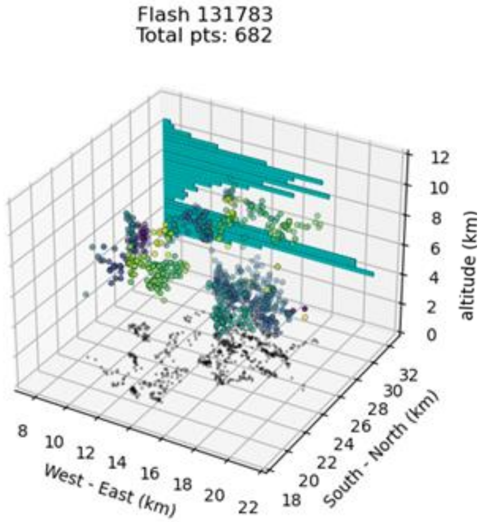
Single satellite (32%)



"Truth": LMA Source Flash

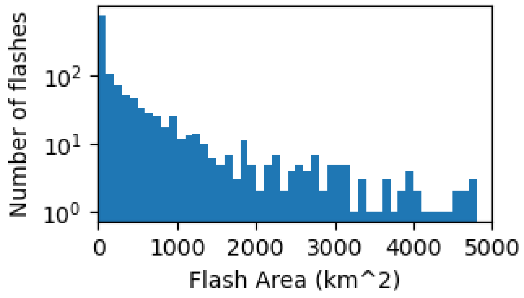


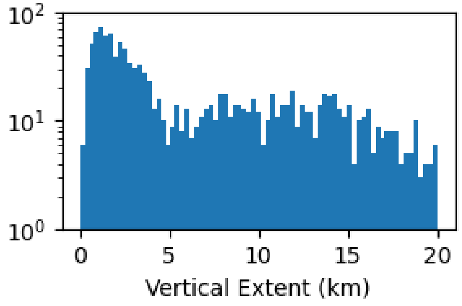
Multi-satellite



TIMES?

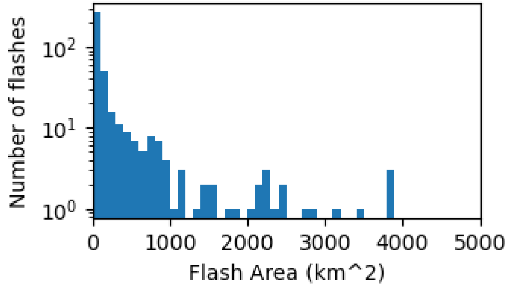
Flash depiction varies with approach

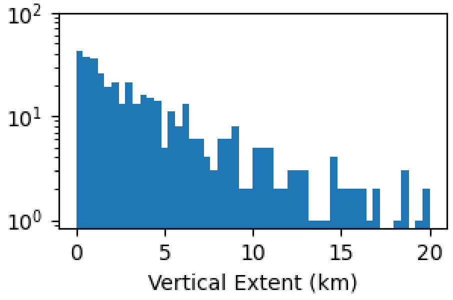




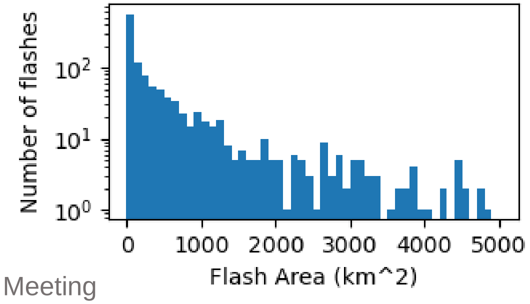
- Multi-sat better depicts channel structure
- Single-sat underestimates vertical extent and flash area

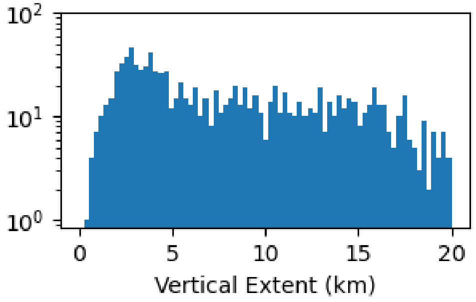
Single satellite





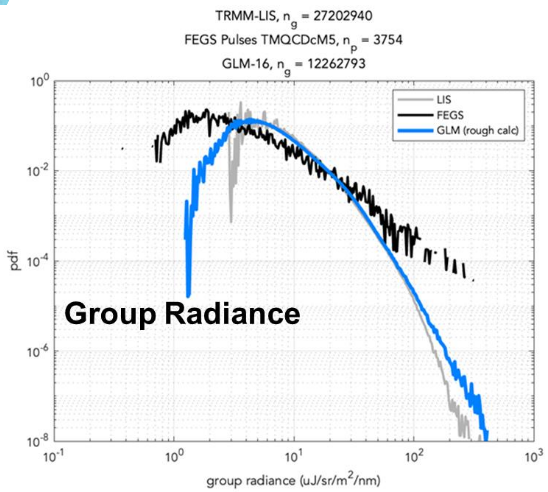
Multi-satellite

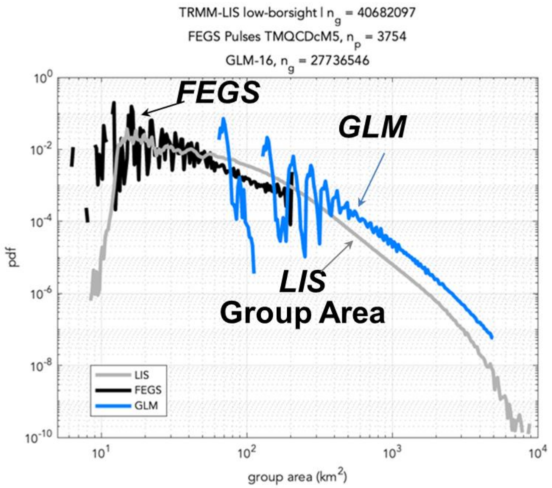




Detecting optically small and faint flashes

The CubeSat Lightning Imaging and Detection Experiment (CLIDE) sensor is being developed for use by CubeSpark



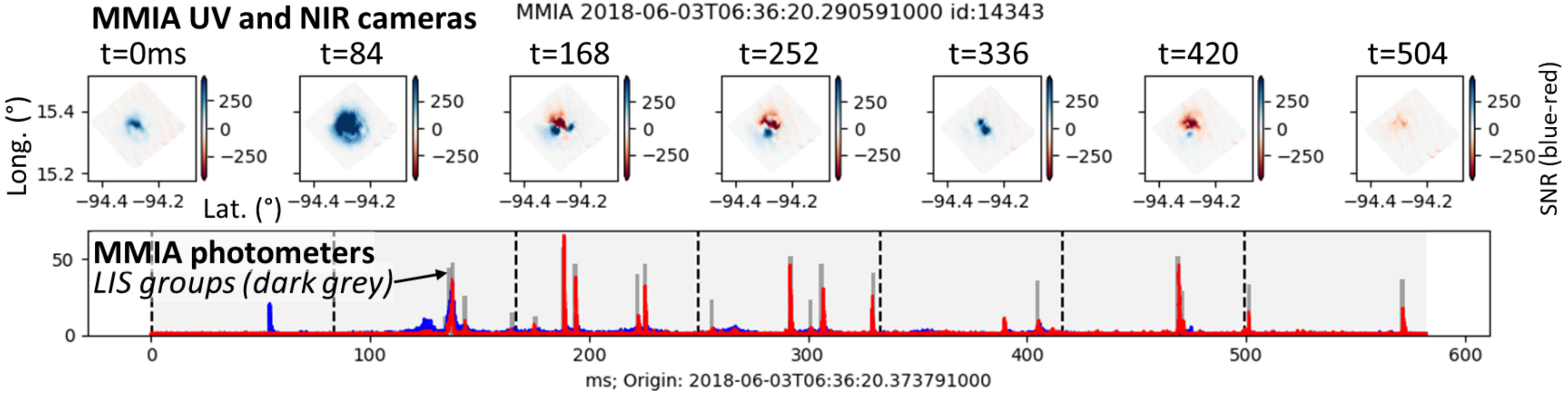


Characteristics of small pulses measured with FEGS spectral lightning observatory

→ Increasing horizontal resolution should improve detection of smaller flashes

CLIDE will have an Ultraviolet imager (337 nm) for detecting cool (streamer) processes that may not be detectable at the standard 777.4-nm

Comparison of ASIM and LIS on ISS



Upcoming FEGS/ALOFT campaign will tell us more about spectral fingerprint of lightning, but need coincident microwave to put it into context

CubeSpark will address existing thunderstorm observational gaps

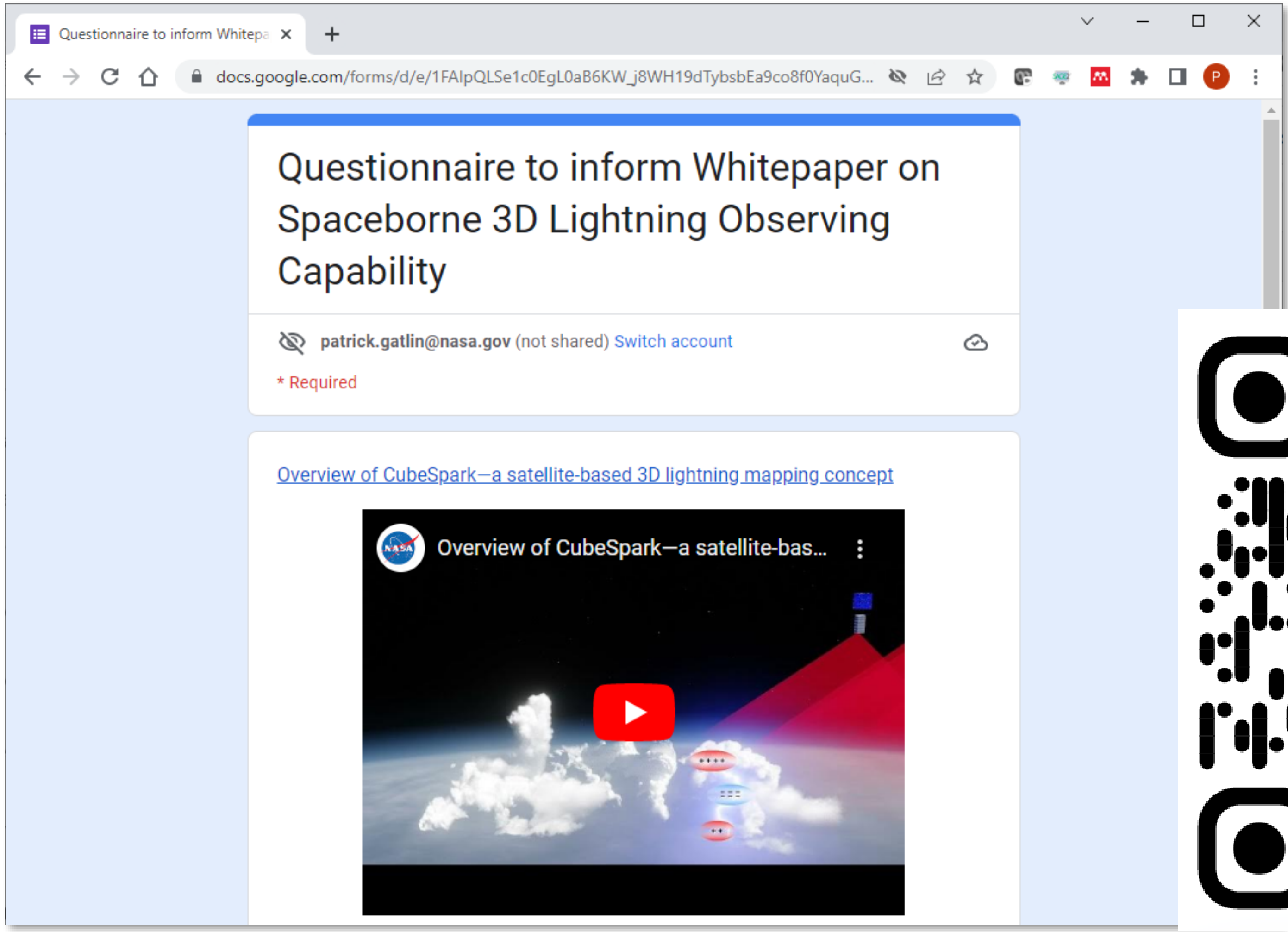
- Enabling Technology:
  - Faster and higher resolution bispectral lightning imager called CLIDE (≥ 1000 fps, ≤ 2 km resolution)
  - Small form factor lightning detectors that can fit on CubeSat platforms
  - Constellation of lightning detectors that see through even the deepest convection
- CubeSpark Observational Capabilities:
  - Identify severe weather signatures on a global scale
  - See inside thunderclouds to map the 3D structure of lightning on a global scale
  - Detect small and low-altitude flashes important for diagnosing storm intensification and severe weather
  - Expands low-Earth orbiting lightning observations to extend at-risk climate record

	Information Extracted from 3D Observation		
Earth Science/Application Benefitted from 3D Observation of Lightning Activity	Flash Altitude	Electrical Charge Structure	Flash Channel Length
Severe Weather	✓	✓	
Precipitation Science	✓	✓	
LNOx (Atmos. Comp & Climate)	✓		✓
Optical lightning detection (Weather forecasting & Climate)	✓		
Wildfire/Winter Weather/Volcanology	✓	✓	

THANK YOU!

We need your input to help make this happen

https://tinyurl.com/cubespark



Questionnaire takes less than 10-15 minutes

BACKUP SLIDES

Airborne Lighting Observatory for FEGS and TGFs (ALOFT)

FEGS = Fly's Eye Geostationary Lightning Mapper (GLM) Simulator
TGF = Terrestrial Gamma-ray Flash

50-h ER-2 airborne field campaign in July 2023 out of Florida base

Principal Investigator: Nikolai Ostgaard, University of Bergen (Norway)
Project Scientist: Timothy Lang, NASA MSFC

GOALS

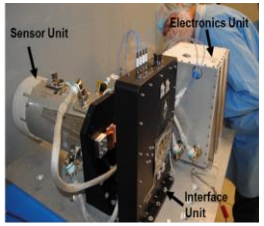
1. Observe TGFs in one of the most TGF-intense regions on the planet.
2. Observe gamma-ray glows in thunderstorms and their relation to TGFs.
3. Perform International Space Station Lightning Imaging Sensor (ISS LIS) and GLM validation using improved suborbital instrumentation (including upgraded FEGS).
4. Evaluate new design concepts for next-generation spaceborne lightning mappers.
5. If relevant instrumentation (e.g., microwave radiometers/radars) is available, make measurements useful to advance convection science from a suborbital platform.

ADDITIONAL INFORMATION: timothy.j.lang@nasa.gov

Comparative Lightning Mapper Technology

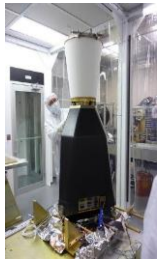
OPTICAL

Optical Transient Detector (NASA MSFC) 1995
- CCD camera @ 777-nm
- 80°x80° FOV
- 1300x1300-km^2 footprint
- 10x10-km^2 nominal resolution
- 500 frames/sec



Lightning Imaging Sensor (NASA MSFC) 1997
- CCD camera @ 777-nm
- 80°x80° FOV
- 550x550-km^2 footprint
- 4x4-km^2 nominal resolution
- 500 frames per second

Geostationary Lighting Mapper (NOAA/NASA) 2016
- CCD camera @ 777-nm
- Full disk FOV (16°)
- 10x10-km^2 nominal resolution
- 500 frames per second



Modular Multispectral Imaging Array (Denmark Tech. Univ./ESA) 2018
- CCD cameras @ 777- & 337-nm
- 80°x80° FOV
- 550x550-km^2 footprint
- 0.4x0.4-km^2 nominal resolution
- 12 frames per second

MTG-I1 Lightning Imager (EUMETSAT) *2022*
- 4 CMOS cameras @ 777-nm
- Full disk FOV (16°)
- 5x5-km^2 nominal resolution
- 1000 frames/sec

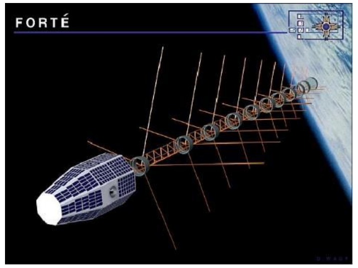
CLIDE (NASA MSFC) 2025
- CMOS camera @ 777-& 337-nm
- 60°x60° FOV
- 600x600-km^2 footprint
- ≤2x2-km^2 resolution
- ≥1000 frames per second
- *Small satellite form factor*

OTD — TRMM / LIS — GOES GLM — MMIA/ASIM — ISS / LIS — CLIDE

1995 — Present — 2028

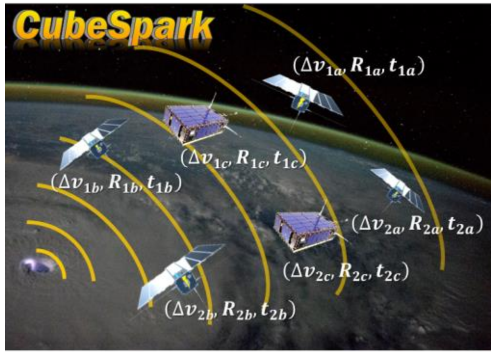
FORTE — CubeSpark

OPTICAL /RF



FORTE (LANL/Sandia/DoE) 1997-2010
- CCD camera @ 777-nm
- 416 frames per second
- 80°x80° FOV
- 1200-km diameter footprint
- 10x10-km^2 resolution
- RF antenna tunable in 20-300 MHz
- Photodiode @ 850-nm

CubeSpark (NASA MSFC/LANL) 2028
- Small satellite constellation
- CMOS camera @ 777- and 337-nm
- ≥ 1000 frames per second
- Resolution:
  2x2-km^2 horizontal
  2 km vertical
- RF antenna tuned to VHF



CubeSat Lightning Imaging and Detection Experiment (CLIDE)

- Purpose: To detect small and optically dim lightning flashes that frequent intense thunderstorms
- Specifications:
  - Center wavelengths: 777.4±0.5 nm; 337±1 nm
  - Spectral bandwidth: ≤ 1 nm FWHM
  - 60 x 60 deg FOV (≥90-sec storm observation time)
  - ≤ 2-km spatial resolution
  - < 1-ms temporal resolution
  - Event detection threshold: ≤ 2 $\mu J\ m^{-2}\ sr^{-1}$
- Being designed for use on small satellite missions like CubeSpark
  - Includes a more compact optics design to reduce size, weight, and cost of telescope
  - Uses faster and higher resolution CMOS detectors with new AI-based storm detection and dynamic sampling strategy