3D Lightning Geolocation with the CubeSpark Constellation

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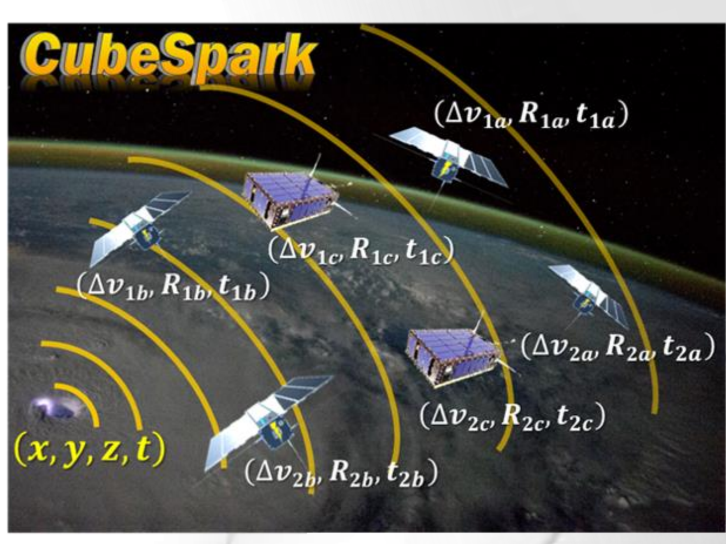
CubeSpark Motivation

The concept of CubeSpark as a next generation lightning mapper is to improve on the 3D accuracy of these observations and make use of the wide electromegantic spectrum of lightning emissions, particularly in infrared (IR), ultraviolet (UV), and radio very high frequencies (VHF).

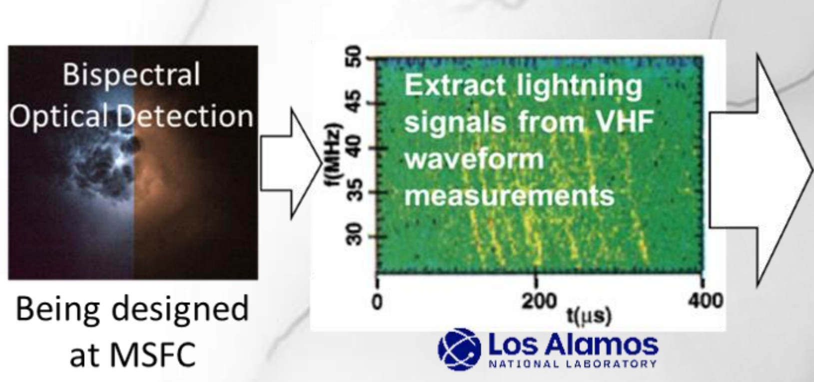
Its primary goals are:

- **< 1-2 km spatial resolution of individual lightning sources**
- **Colocated VHF sensor and combined UV/IR optical imager**

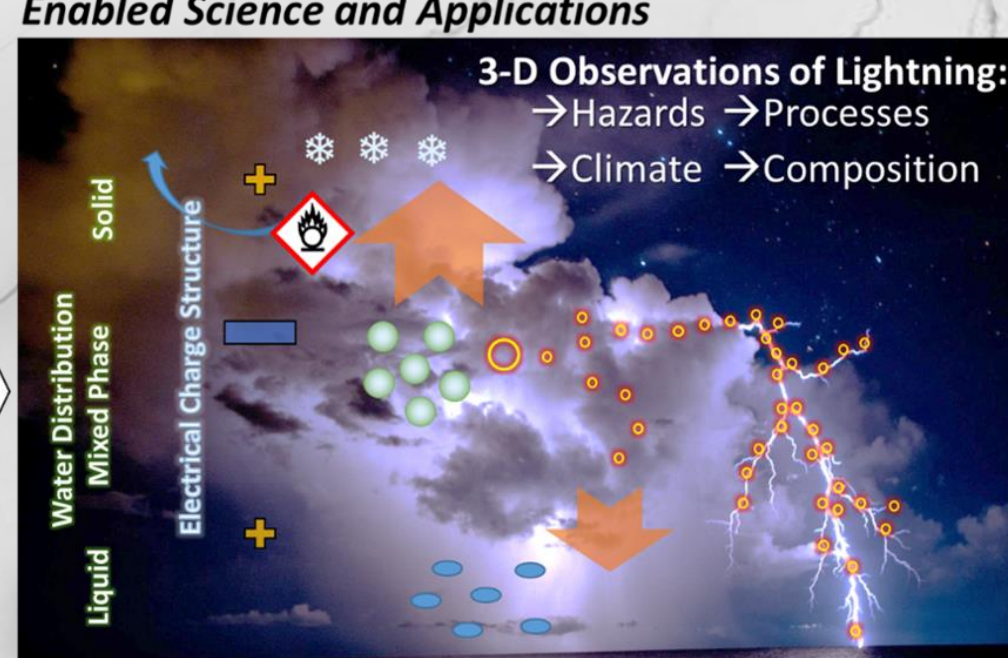
Science/Application Benefitted	Flash Altitude	Charge Structure	Channel Length
Severe Weather	✓	✓	
Precipitation Science		✓	
LNOx (Atmos. Comp & Climate)	✓		✓
Optical lightning detection (Weather forecasting & Climate)	✓		
Wildfire/Winter Weather	✓	✓	



Measurement Concept



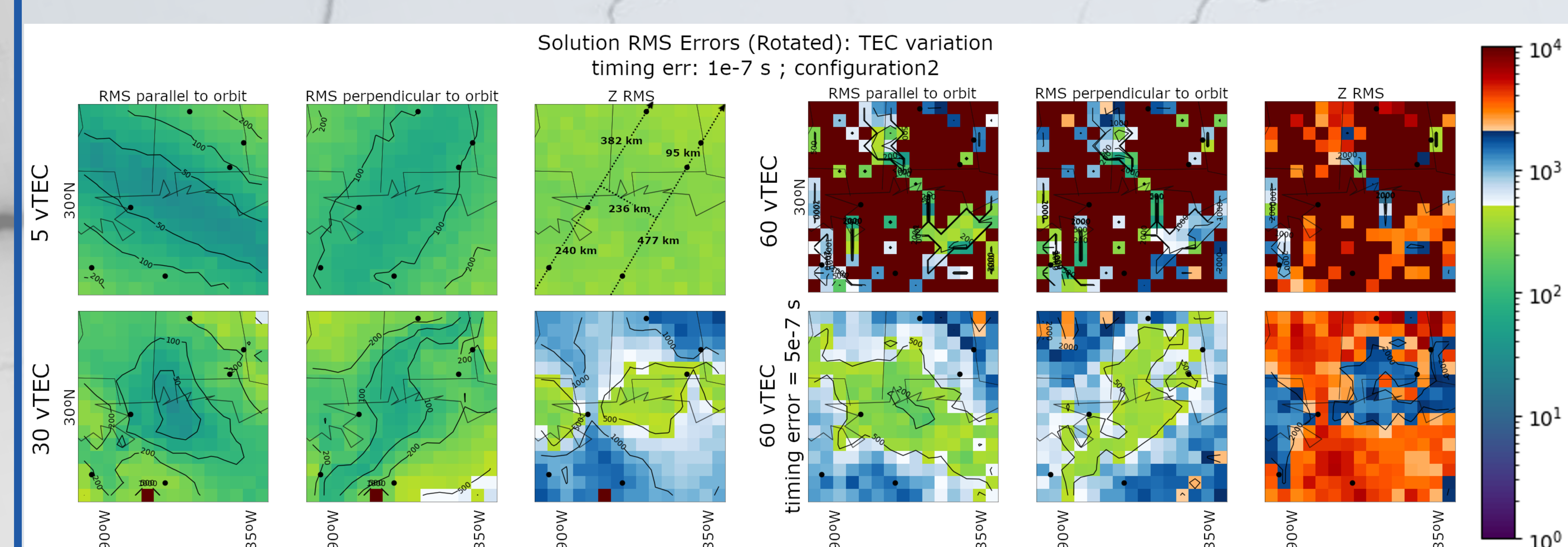
Enabled Science and Applications



Ionospheric Propagation & Geolocation Simulations

Simulation work of these methods is largely based on the Lightning Mapping Array (LMA) simulation package (Chmielewski & Bruning 2016), modified for orbiting detectors.

- Level-0 study by MSFC Advanced Concepts Office explored constellation design optimized for low Earth orbit (LEO).
- Simulates individual, high-power VHF sources in the 600 x 600 km grid below the network.
- Satellite spacing is varied along two orbital planes to reduce baseline symmetry



Ionospheric dispersion of RF signals is robustly simulated and corrected first order to determine the estimated time of arrival at each satellite.

- Ionospheric electron density is simulated at 5, 30, and 60 total electron count units (TECU = 10^{16} electrons/m^2).
- Arrival time is dithered further to account for instrumental uncertainty (conservatively 100 ns) before being used by time-of-arrival (TOA) methods to locate sources. This can be relaxed to 500 ns to improve convergence rate (see right panels).

3D Mapping Methods

1 satellite	2 satellites	3 satellites	4 satellites	5 satellites	6 satellites
Reflected pulse solution	Reflected pulse solution (averaged)	Reflected pulse solution (averaged)	Reflected pulse solution (averaged)	Reflected pulse solution (averaged)	Reflected pulse solution (averaged)
	Constrained TOA + optical (0 DoF) 🚫	Constrained TOA + optical (1 DoF)	Constrained TOA + optical (2 DoF)	Constrained TOA + optical (2 DoF)	Constrained TOA + optical (2 DoF)
			Pure TOA method (0 DoF) 🚫	Pure TOA method (1 DoF)	Pure TOA method (2 DoF)

Reflected Pulses:

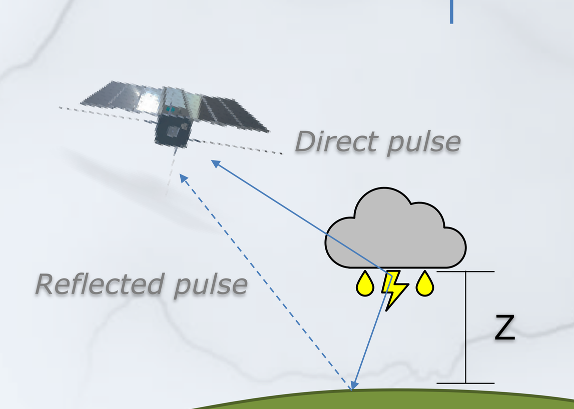
- Uses Earth-reflected pulse to calculate time and source altitude
- Up to ~32% of sources have reflected pulses

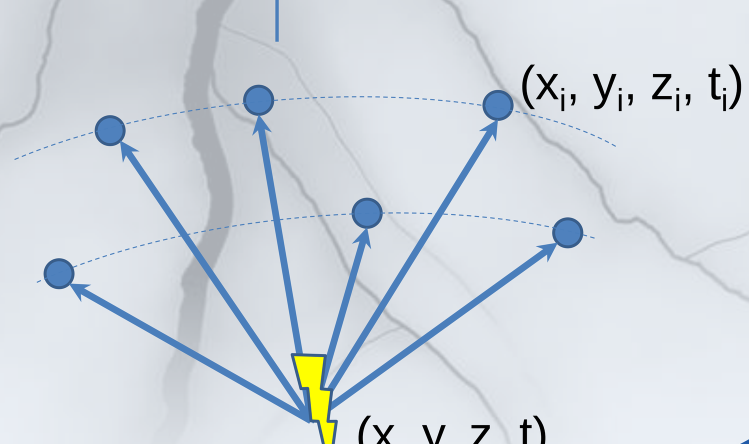
Constrained time-of-arrival (TOA):

- Horizontal position constrained by optical imager
- Time and altitude overdetermined by signal arrival times

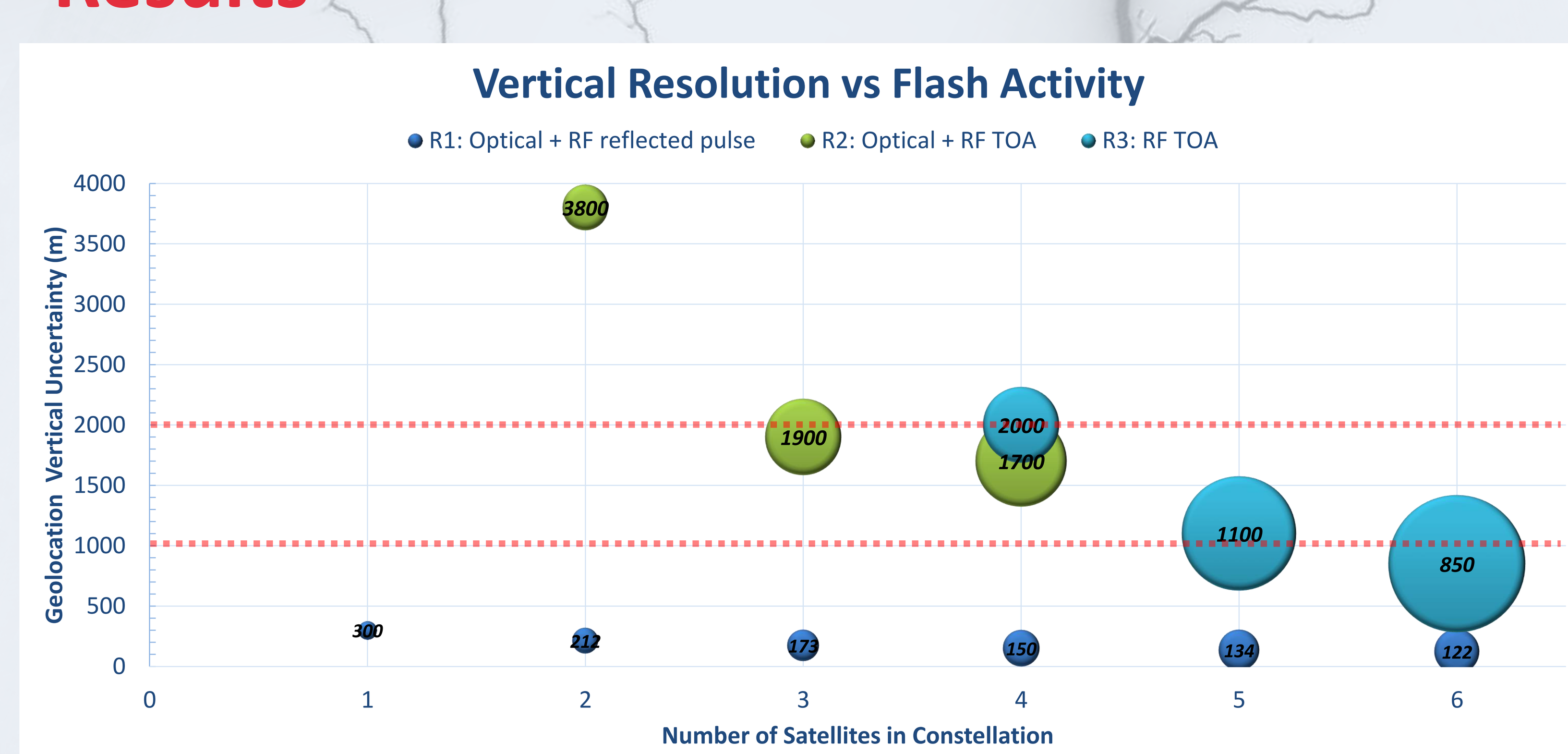
Pure TOA method:

- Source locations and times overdetermined from 5+ RF measurements
- 3D Reconstruction depends on relative signal arrival times





Results



Pure-VHF TOA approach(5-6 satellites):

- **~260 m** horizontal, **~980 m** vertical error
- Not feasible for <5 satellites

Constrained TOA approach (3-4 satellites)**:**

- **580 m** horizontal, **~1,800 m** vertical error
- Not feasible for <3 satellites

Reflected pulse approach (1-2 satellites):

- **580 m** horizontal, **~260 m** vertical error
- Fewer resolvable sources

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