Low-Frequency Sound from Explosive Sources

MTV Workshop, 2021

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Introduction, Motivation, Relevance

TA3. Nuclear Explosion Monitoring

Explosion monitoring and forensic analysis are traditionally relevant mission across DOE, DOD, and other US and international agencies (e.g. CTBTO).

TA3.1. Infrasound

- Address diversity of emplacement conditions and delivery systems for low, high, and nuclear explosives.
- Apply new blast pulse scaling and parametrization to near-surface and airborne stationary, subsonic, supersonic, and hypersonic explosive sources.

Ph.D. Students on Infrasound Thrust

  - Kei Takazawa, Jonathan Tobin, Sarah Popenhagen, Yusuke Hatanaka

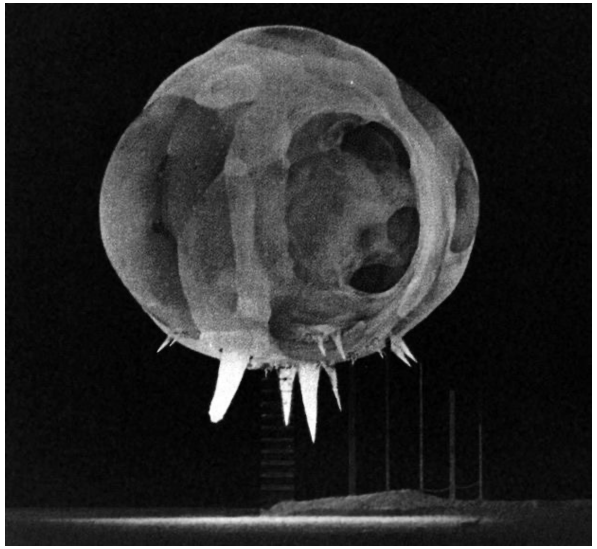
Lab Collaborations

- INL: David Chichester, Edna Cardenas, Scott Watson.
- LLNL: Keehoon Kim, Steven Magana-Zook.
- NNSS: Cleat Zeiler, Kale McLin.
- SNL: Daniel Bowman.

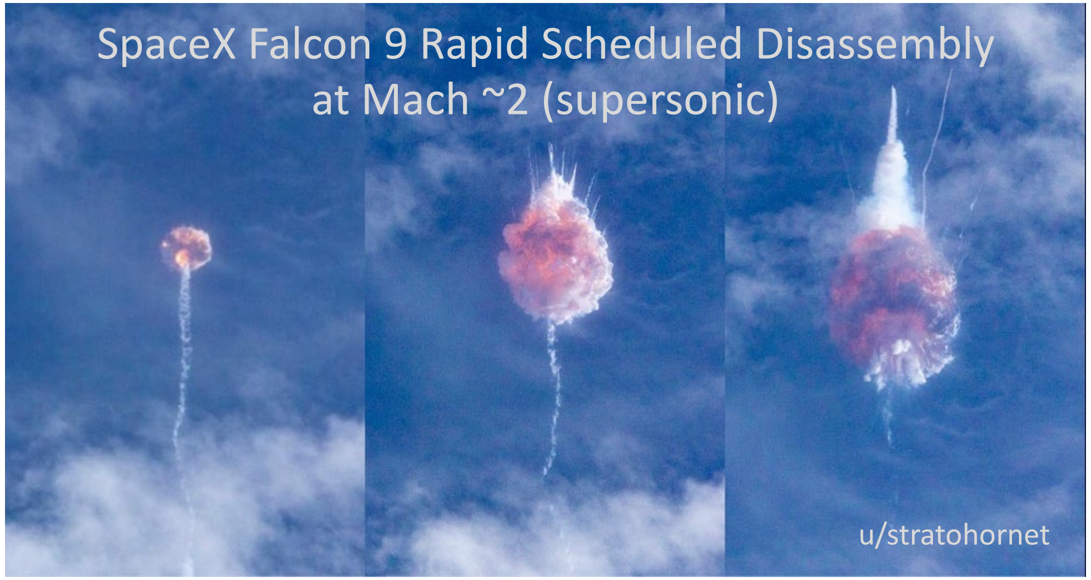
Blasts: from kilotons to kilograms

Modernize geophysical sensing systems and methods that can be deployed globally to effectively monitor explosive events and fuel cycle activity.

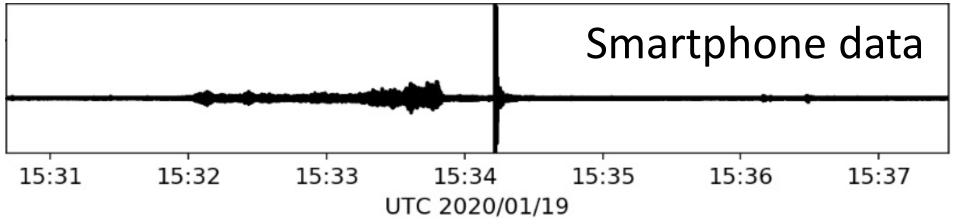
Tumbler Snapper
(LLNL YouTube Channel)



High Explosive NE Proxies at NNSS & INL



Supersonic Propellant Blast Proxy



http://redvox.io/@/a3a8

Launch and photo by D. Bowman.

Airborne Collection Platforms

Ongoing Laboratory Collaborations

- LLNL blast pulse R&D, continuation and maturation from CVT.
- NNSS controlled blasts, 2020. Smartphone collection and analysis.
- SNL airborne platforms collection of NNSS blasts. Smartphone collection and analysis.
- INL controlled blasts, 2020. Smartphone collection and analysis.
- INL UAS signatures, 2020. Smartphone collection and analysis.
- INL and MINOS, Nashville uncontrolled blast, 2020. Smartphone collection and analysis.
- Supersonic and hypersonic signatures (shocks). Smartphone collection and analysis.

NNSA National Nuclear Security Administration

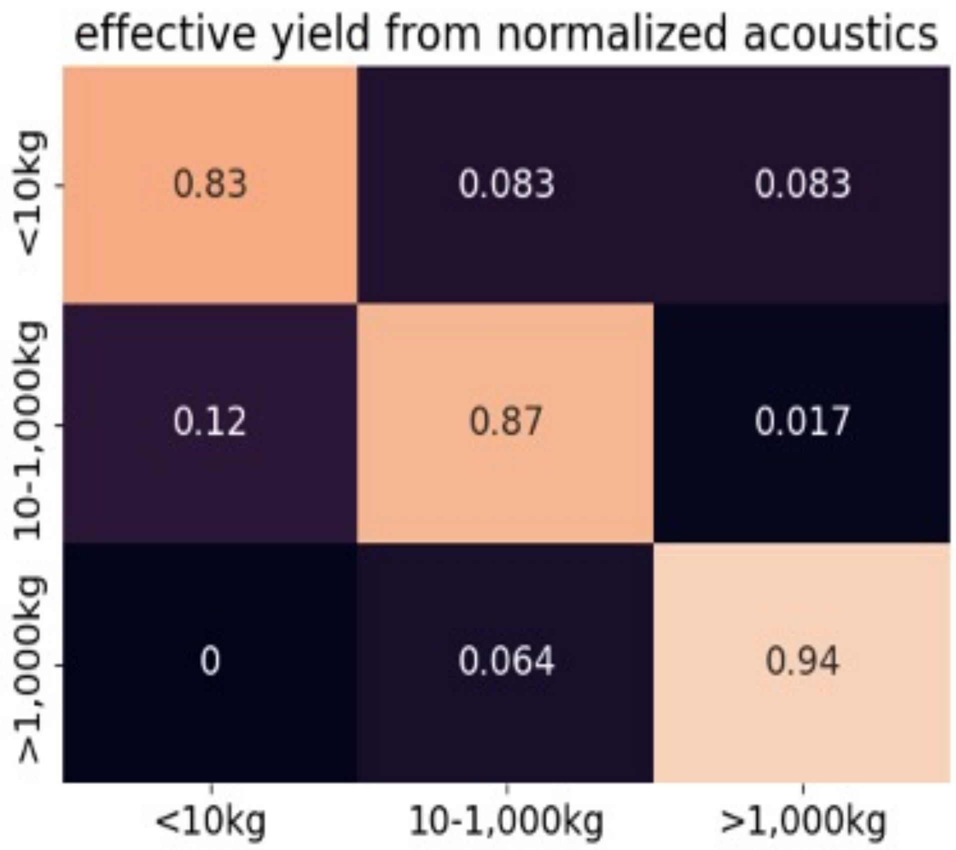
Technical Approach

Collect, Analyze, Develop, Publish

- Kim, K, A. R. Rodgers, M. A. Garces, and S. C. Myers (2021, submitted). Empirical Acoustic Source Model for Chemical Explosions in Air, Bull Seism. Soc. Am.
- Takazawa S., M. A. Garcés et al. (2021, in progress). Constant-Q Frequency Bands for Spectral Representations of Explosions Recorded on Smartphones for Machine Learning Application (WIP)
- Garcés, M. A., D. Bowman, A. Christe, T. Yoshiyama, B. Williams, M. Colet, J. Tobin, Samuel Takazawa, S. Popenhagen, K. McLin, C. Zeiler (2021, in progress). Skyfall 2020: Smartphone data from a 30 km balloon drop. For submission to MDPI Sensors.
- Tobin, J., Takazawa, S., Cardenas, E., Chichester, D., Garcés, M. A., et al. (2021, in progress). Acoustic Insight on Nuclear Research Reactor Activity.
- Popenhagen, S. and M. A. Garcés (2021, in progress). Rocket Signatures Collected by Smartphones.
- Garcés, M. A. (2020). Quantized constant-Q Gabor atoms for sparse binary representations of cyber-physical signatures, Entropy, 22, 936; doi:10.3390/e22090936. https://pypi.org/project/libquantum/
- Schnurr, J. M., K. Kim, M. A. Garcés, A. Rodgers (2020). Improved parametric models for explosion pressure signals derived from large datasets, Seism. Res. Lett., https://doi.org/10.1785/0220190278

UH Student Posters (this meeting)

- Takazawa, S., M. Garcés, K. Kim, **Explosion Yield Estimation using Machine Learning Methods**
- Tobin, J., M. Garcés, D. Chichester, J. Hix, Scott Watson, **Inferring UAV Position Relative to Smartphone Sensors Based on Acoustic Characteristics**.
- Popenhagen, S. and M. A. Garcés. **Rocket Ignition Detection Using Data Collected by Smartphones.**

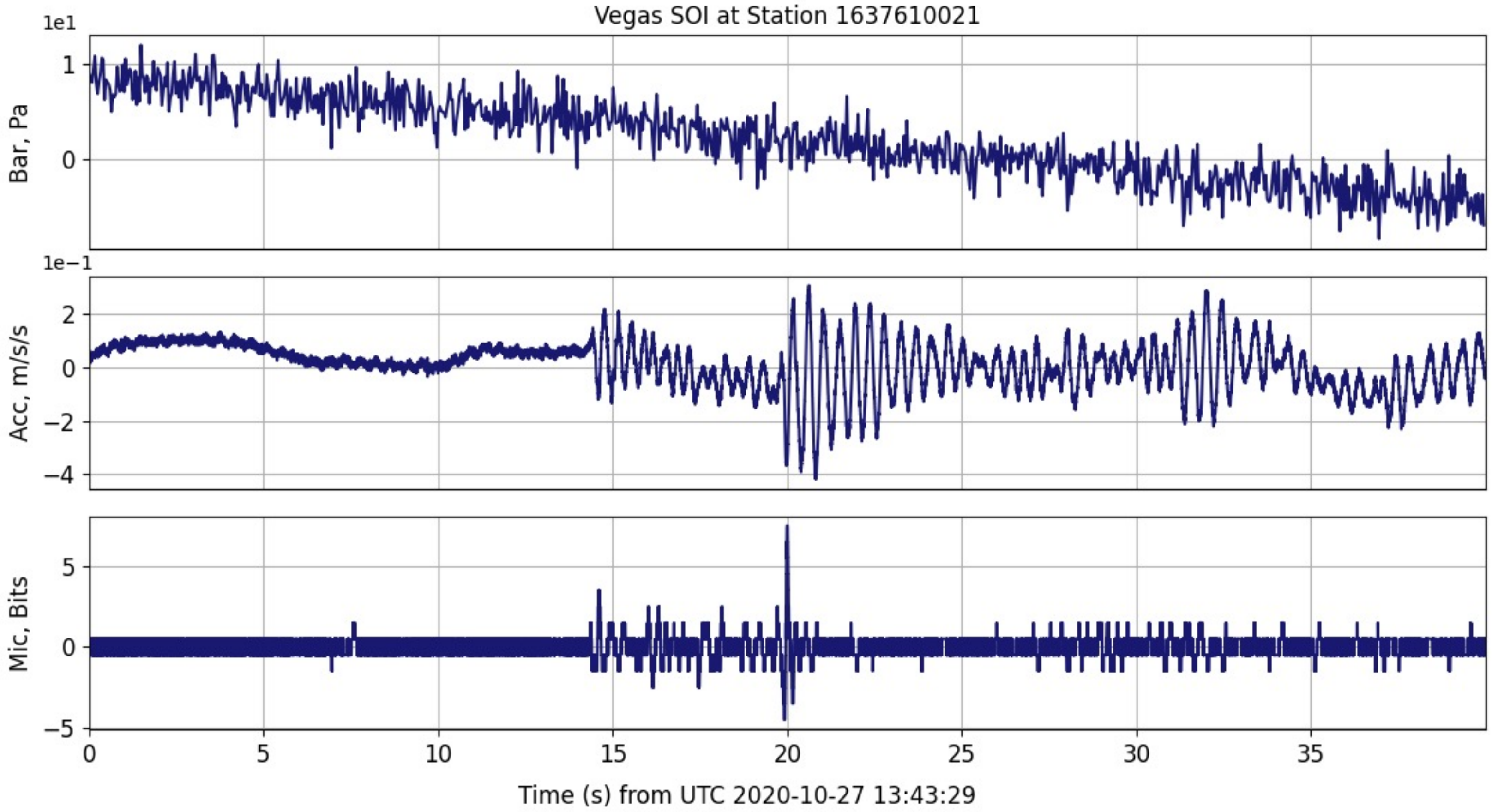


2020 Collection Highlights: INL Blasts and UAV

- Excellent collaboration and tech transfer cycle
- More collections anticipated in 2021 with new apps (FY21Q3)
- Papers and presentations in progress
- Nashville at MINOS net

2020 Collection Highlights: NNSS and SNL

- Airborne platforms recordings of surface blast: Samsung S10



2020 Collection Highlights: NNSS and SNL

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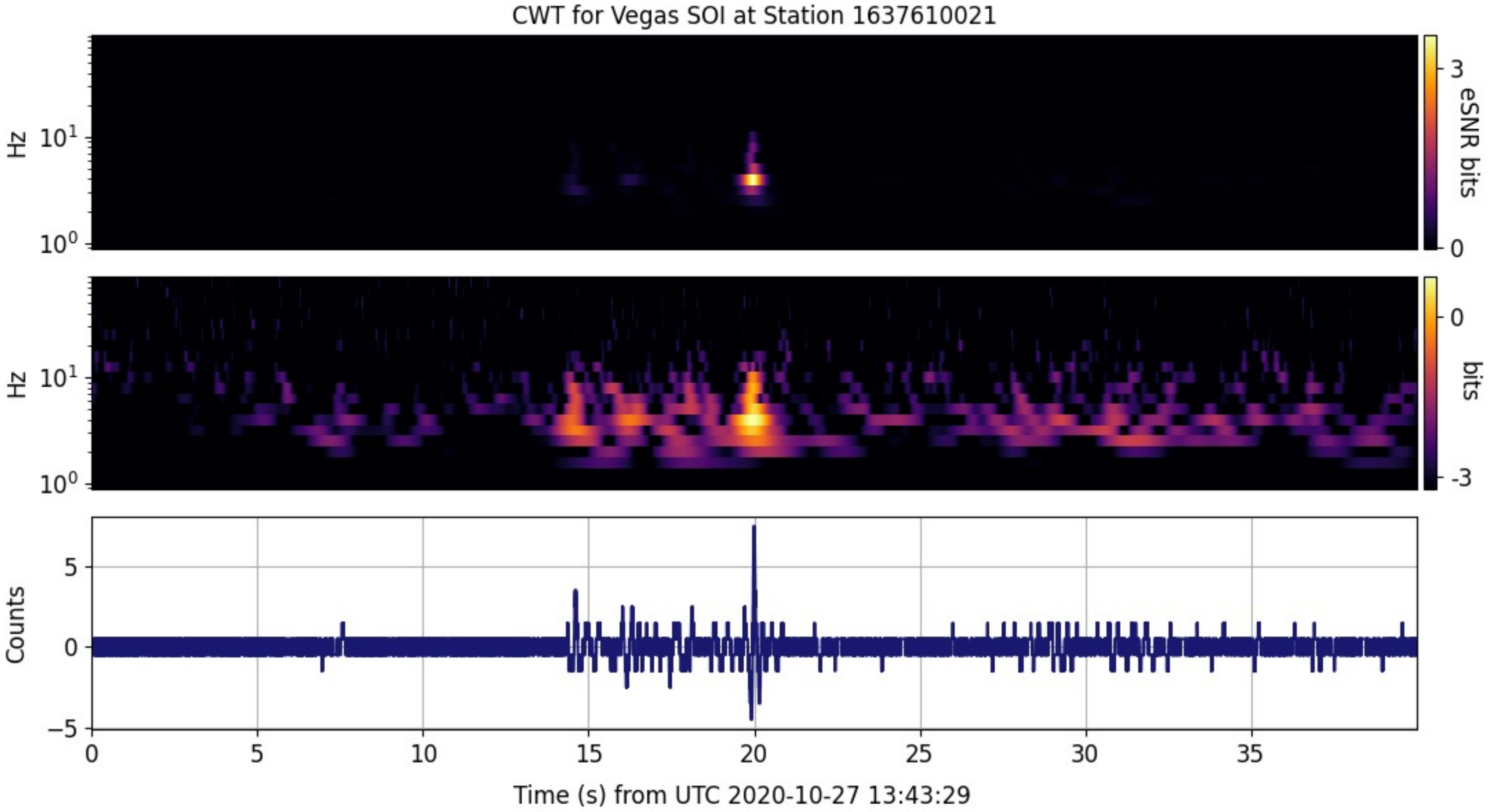
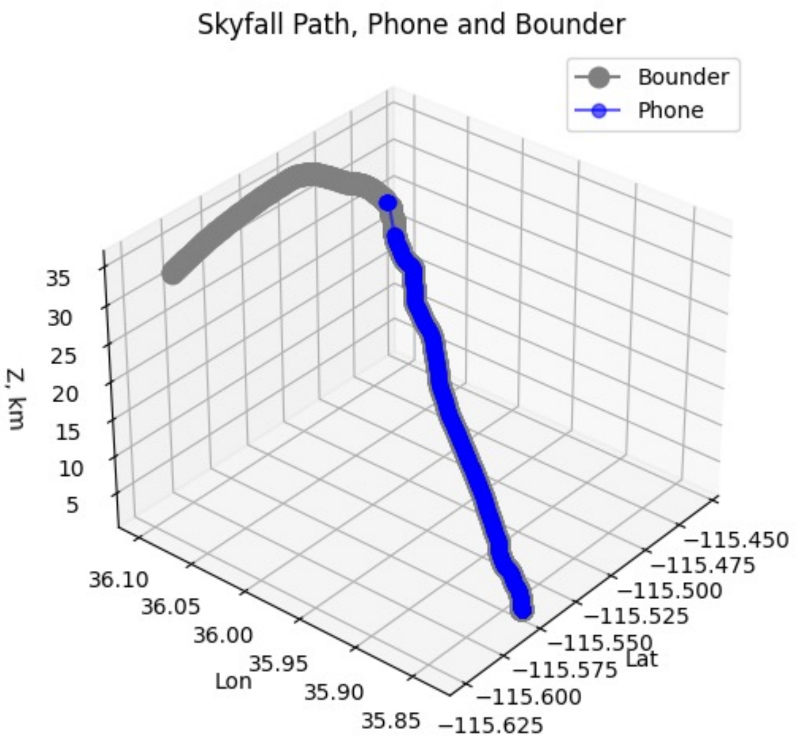
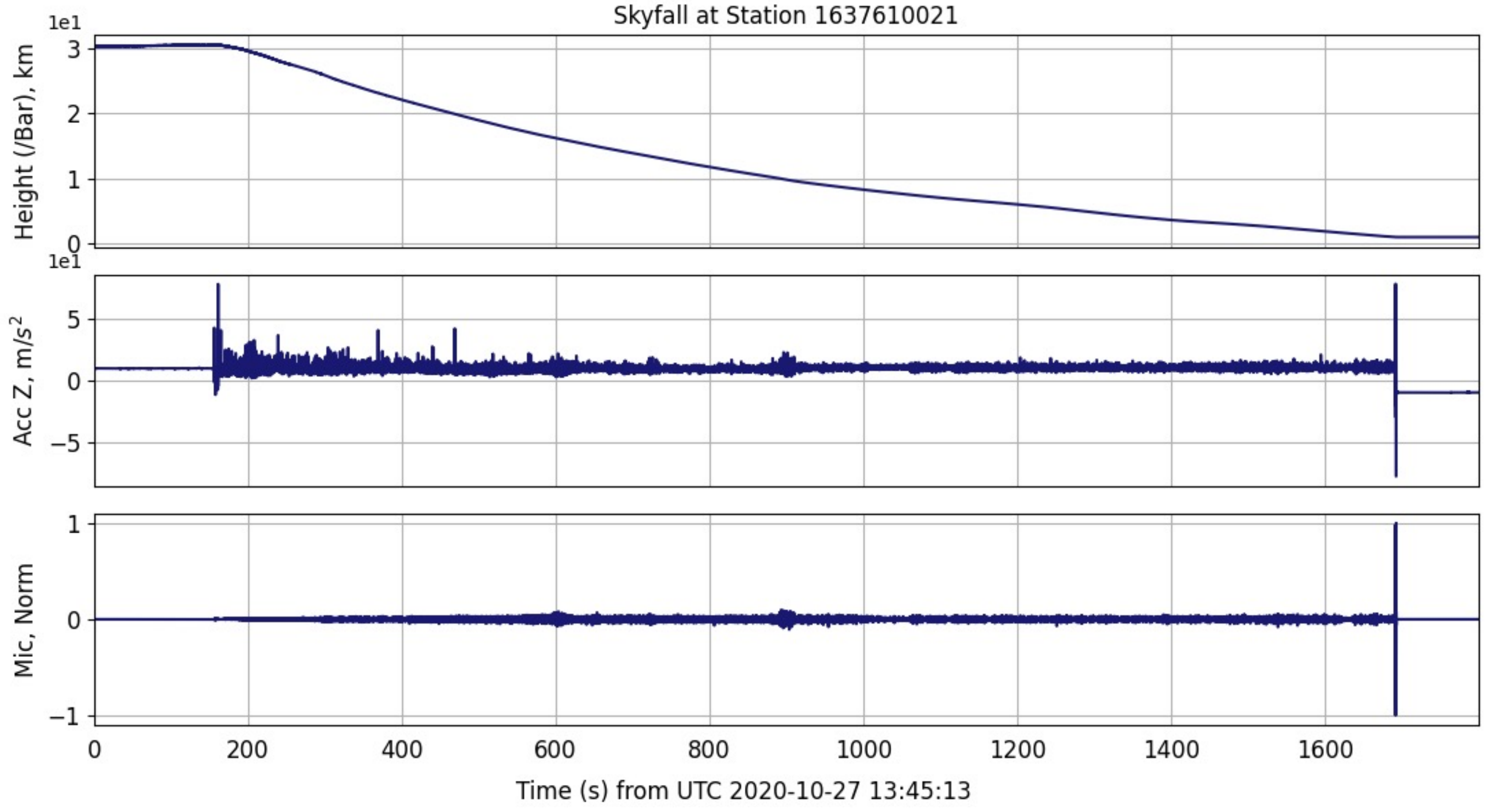


2020 Collection Highlights: Skyfall

- Stratospheric (30km) drop test of Samsung S10

Garcés, M. A., D. Bowman, A. Christe, T. Yoshiyama, B. Williams, M. Colet, J. Tobin, Samuel Takazawa, S. Popenhagen, K. McLin, C. Zeiler (2021, in progress). **Skyfall 2020: Smartphone data from a 30 km balloon drop**. For submission to MDPI Sensors.





Hypersonic shocks

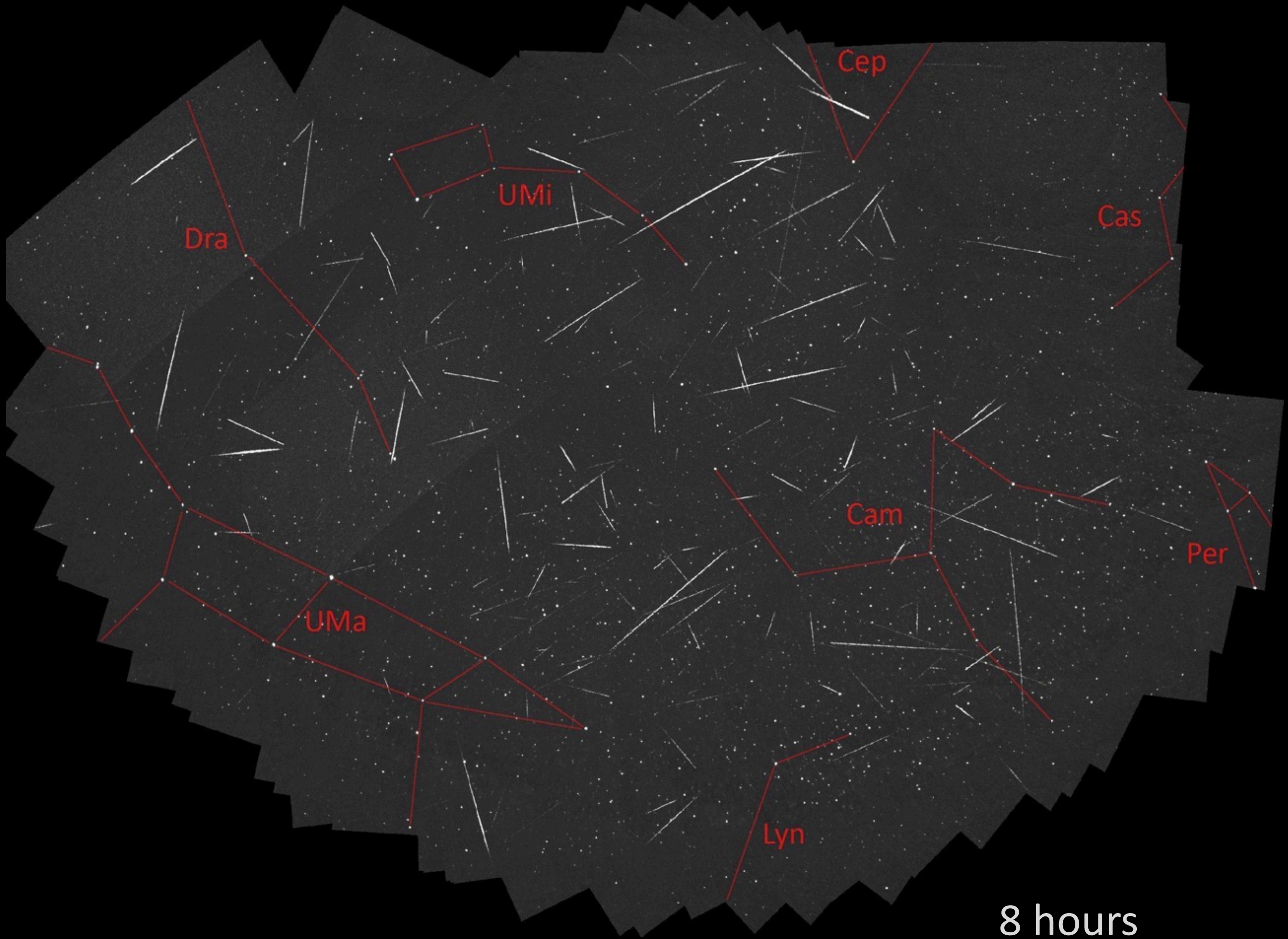
- Start with acoustic parameters from formulations for hypersonic meteor impacts
- Hypersonic: Mach = v/c > 5
- Earth's speed: 30 km/s (~Mach 100)
- Leonids speed: 72 km/s (~Mach 200)
- Mean specs for meteor impacts with Earth:

➢ Diameter: 2 x 10^{-2} cm

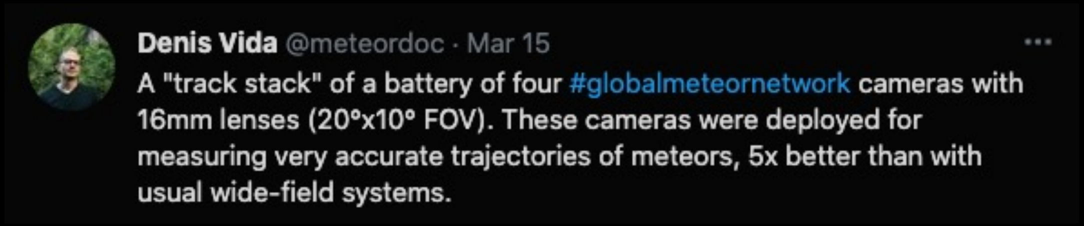
➢ Mass: 10 micrograms

➢ Impact rate: 10^8/day

➢ Deposition rate: 10^5 tons/year



8 hours


Denis Vida @meteordoc · Mar 15
A "track stack" of a battery of four #globalmeteornetwork cameras with 16mm lenses (20°x10° FOV). These cameras were deployed for measuring very accurate trajectories of meteors, 5x better than with usual wide-field systems.

Exotic Hypersonics

- Axion Quark Nuggets (AQN) are candidates for **dark matter**.
- They are dense (tiny neutron stars)
- It has been postulated that AQN antimatter annihilation on impact with Earth can generate acoustic and seismic signals.
- Predicted atmospheric acoustic parameters are derived from formulations related to those of hypersonic **meteor** impacts.
- Estimated infrasonic frequency of 5 Hz and overpressure of 0.3 Pa for large ($B=10^{27}$), infrequent dark matter nuggets are within present-day sensor specs.
- Proverbial needle in the haystack.

Many thanks to John Learned!

Infrasonic, acoustic and seismic waves produced by the Axion Quark Nuggets

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Preprint submitted to Elsevier *October 13, 2020*

Key specs for spaceborne Earth impacts:

- AQN Baryon number (B): 3×10^{24} - 10^{28}
- AQN Spectrum: (10-50) keV (beyond 1-10 eV optical)

Expected values:

- AQN size, mass, B: 10^{-5} cm, 10 g, 10^{25}
- AQN impact rate: 1/day/(100km x 100km)
- AQN deposition rate: 5×10^{2} tons/year
- Meteor size, mass: 2×10^{-2} cm, 10 microg
- Meteor impact rate: 10^{8}/day
- Meteor deposition rate: 10^{5} tons/year

National Nuclear Security Administration

Impact and Conclusions

- Advancing explosion monitoring mission.
- Addressing emerging WMD delivery systems.
- Facilitating agile collections.
- Internships, workshops, cross-disciplinary collaborations.
- Tech transfer: due to pandemic, all collections were performed by Lab personnel.
- Coordination with DOE, DOD and other Federal agencies (e.g. Nashville blast).

Next Steps: From statement of work

- Y1: Build and validate generalized signal-specific models and methods using transportable, scalable metrics (Garces, 2020; Schnurr et al., 2020)
- Y2: Integrate traditional and mobile smartphone networks for localization of stationary signals (Ongoing)
- Y3: Expand network detection, localization and characterization to moving sources (Initiated)
- Y4: Expand network detection, localization, and characterization to moving sources and moving sensor networks (e.g. balloon and ocean glider systems)
- Y5: Fuse physics and information theory principles to expedite rapid source identification at regional and global scales from heterogeneous sensor network data

Acknowledgements

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