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# QUANTIFYING ASTEROID IMPACT ENERGY: IMPLICATIONS FOR PLANETARY DEFENSE

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Based on the presentation "*Quantifying bolide yield through infrasound analysis: Implications for planetary defense*"

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LDRD LABORATORY DIRECTED RESEARCH & DEVELOPMENT
WHERE INNOVATION BEGINS

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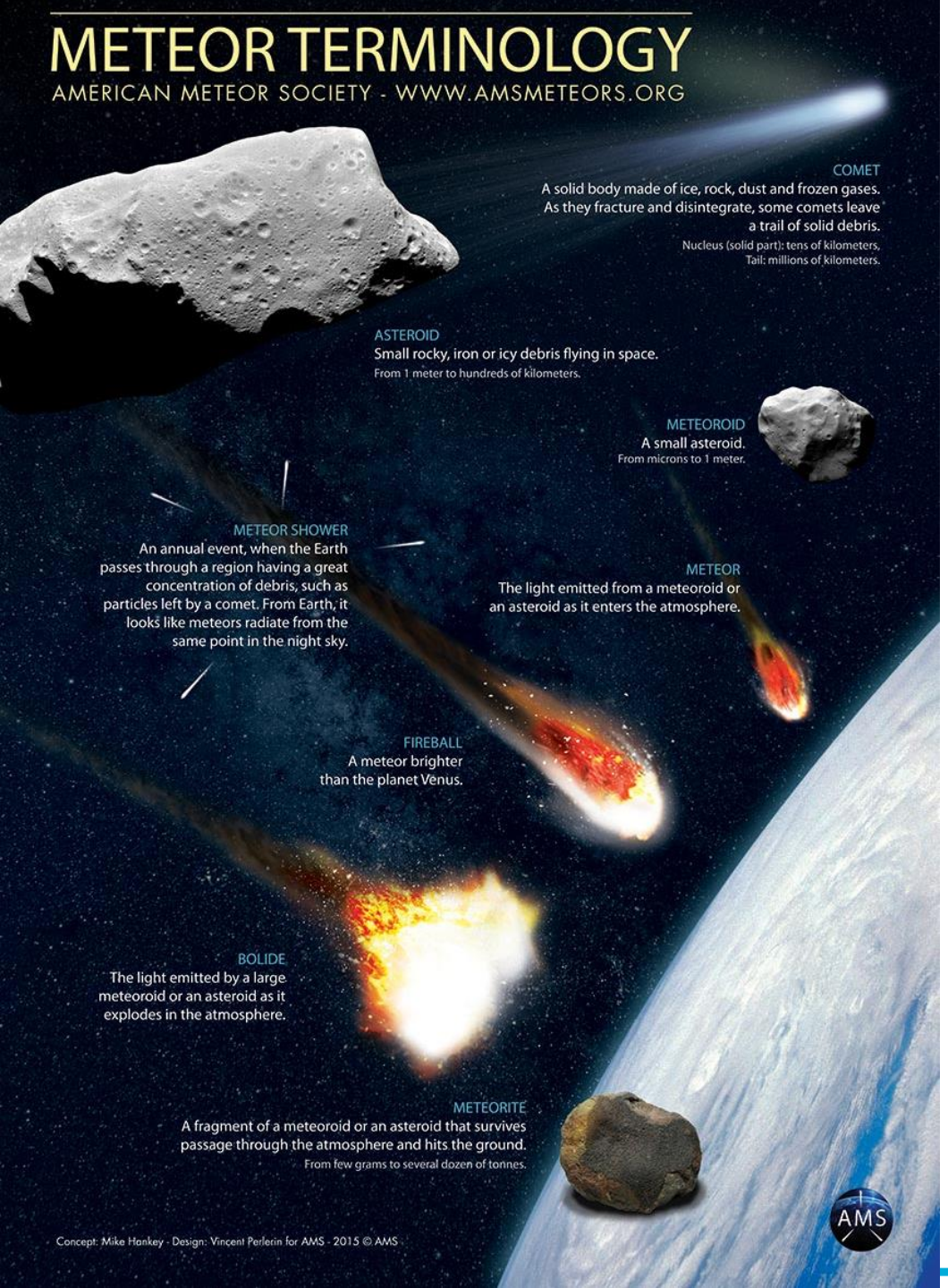



# METEOR-WHAT?

- Rocky, icy and metallic fragments entering from space impact Earth's atmosphere daily
  - After entering the atmosphere, these objects heat up and interact with air molecules to produce a luminous path called a **meteor** or a **shooting star**
  - **Fireballs and bolides** – exceptionally bright meteors
  - **Meteoroids** – objects up to 1 meter in diameter (sizes are from dust and sand grains to an SUV tire); these impact most frequently
  - **Asteroids** – objects larger than 1 meter in diameter
  - **Meteorite** – if the meteoroid survives its passage through the atmosphere and lands on the surface
- Most objects vaporize in the atmosphere, but larger ones can pose threat → asteroids and large meteoroids generate shock waves
- Good news – larger objects are less frequent
- Bad news – larger objects are much more destructive

Lidz, Franz (2019-01-09) "The Oldest Material in the Smithsonian Institution Came From Outer Space". Smithsonian

# CHELYABINSK BOLIDE

- On Feb 15, 2013 impacted over Chelyabinsk, Russia
- The asteroid came from the direction of the sun, which makes it difficult to spot *a priori*
- It was very energetic – 440 kt of TNT equivalent, which is nearly 30x greater than the Hiroshima bomb
- Caused injuries and property damage, 1000s of windows broken
- Its entry at a shallow angle made it even more destructive
- The object was 18 m in diameter (size of a house)

mage credit: Alex Alishevskikh



Factory wall after it was hit by the blast wave. Image credit: Константин Кудинов

Image credit: Pospel

Image credit: Nikita Plekhanov

# OBSERVATIONS OF ASTEROIDS

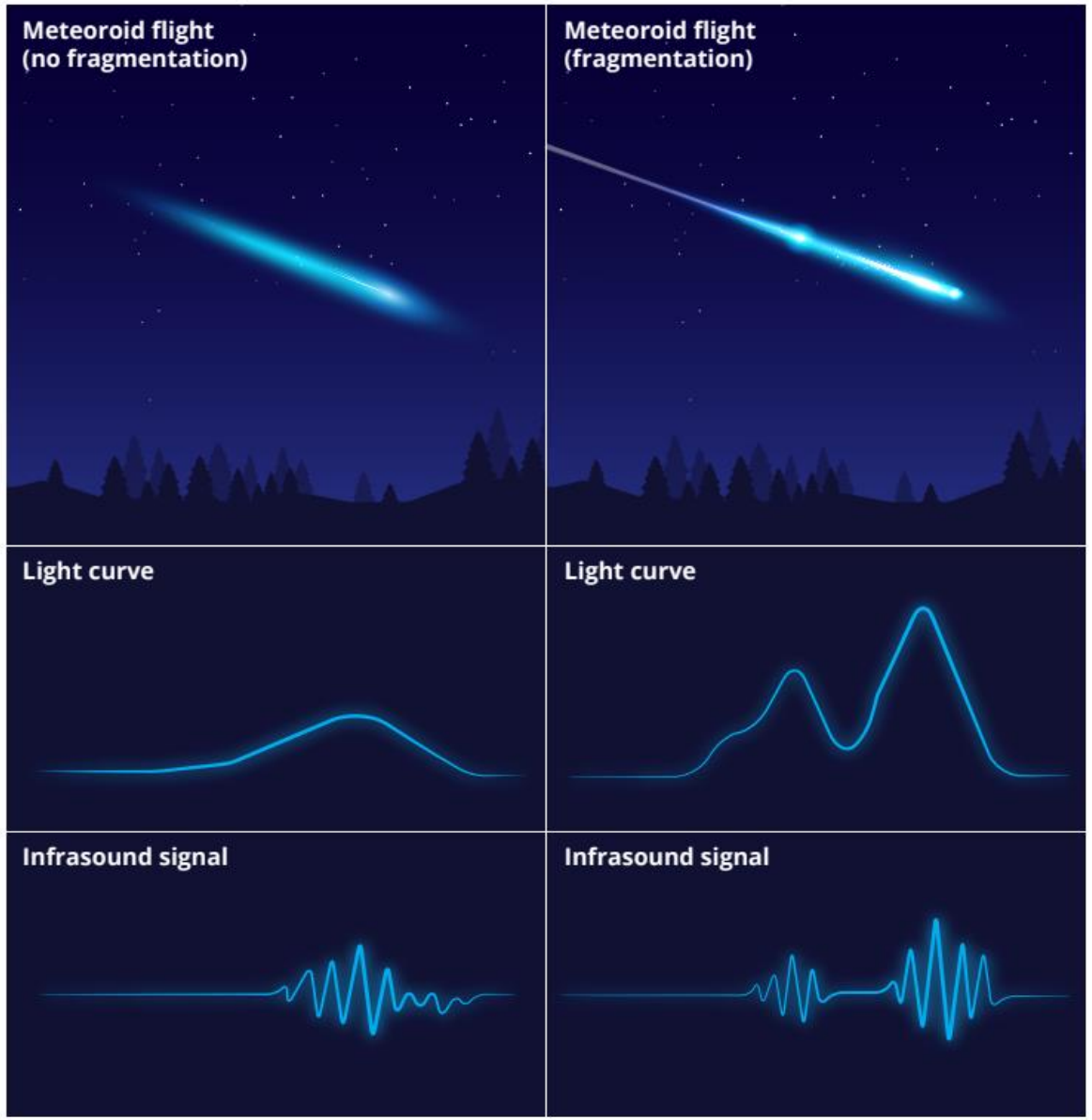
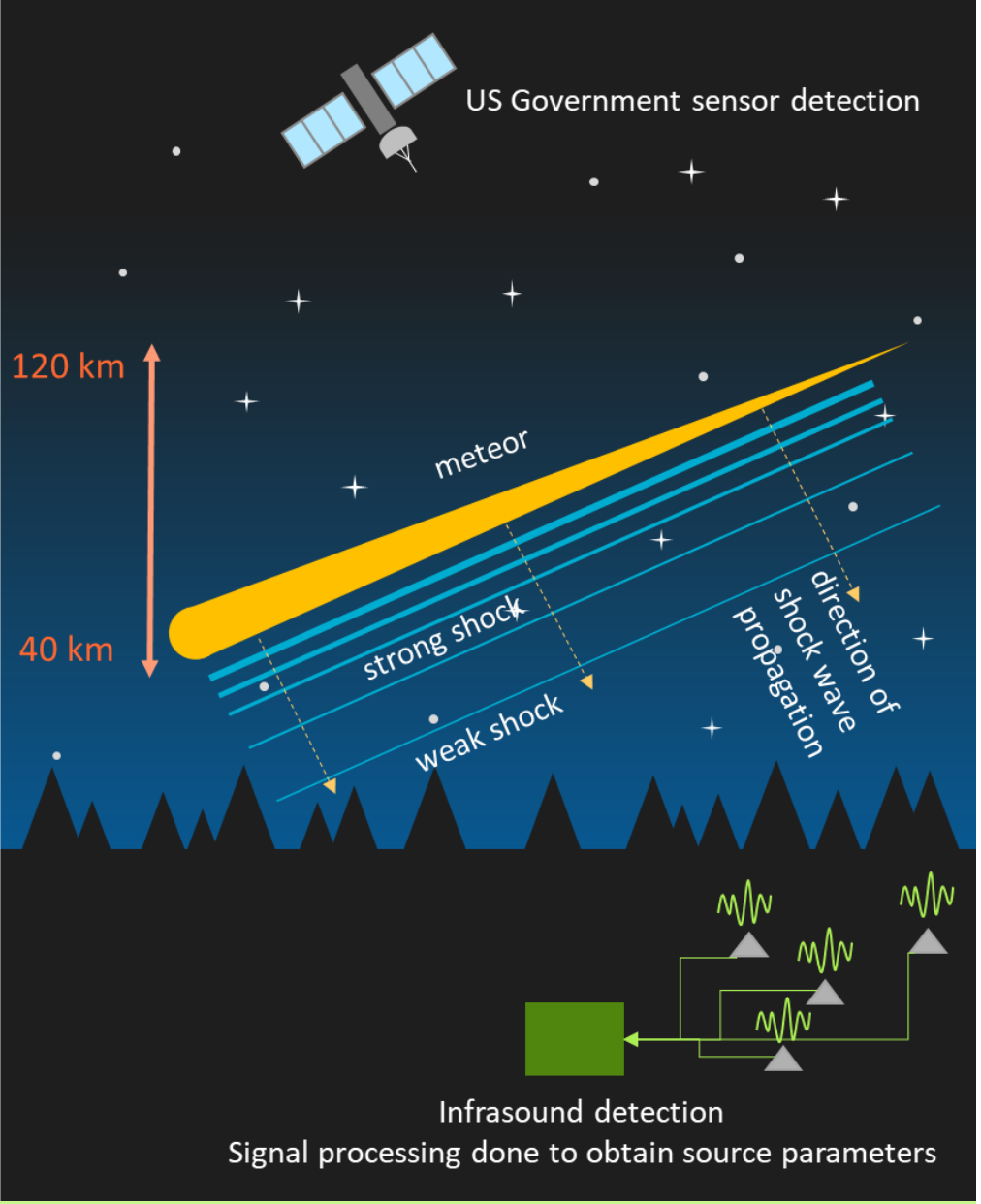



Figure adapted from Silber, E. A. (2024) The Utility of Infrasound in Global Monitoring of Extraterrestrial Impacts: A Case Study of the 2008 July 23 Tajikistan Bolide, The Astronomical Journal, Vol. 168, No. 1, doi: 10.3847/1538-3881/ad47c3

- There is an ongoing effort to better characterize asteroids
- Events can be recorded and documented through various means of observation
  - Space-based observations (US Government sensors, GLM)
  - Ground-based observations (all-sky cameras (still and video), radar, casual witnesses, seismic and infrasound)
  - There is no perfect approach that would provide all answers we seek
- Various observational methods can be combined to gather a better picture
- However, many questions remain unanswered, and therefore it is imperative to leverage all approaches
- Infrasound is one of the essential sensing modalities because it can offer global coverage, and can be used to estimate impact energy

# INFRASOUND: A KEY TOOL IN MULTI-MODAL ASTEROID OBSERVATIONS




**Infrasound is low-frequency sound below the range of human hearing, typically below 20 Hz. This unique capability makes infrasound an invaluable tool in asteroid observation**

## Detection of asteroid impacts

- Infrasound can be used to detect low frequency sound waves generated by asteroid impacts
- Infrasound can travel long distances and provide data on the timing and location of an event

## Characterizing impacts

- By measuring infrasound signals (period and amplitude), it is possible to infer the energy of an asteroid
- This information is vital for understanding potential threats to Earth

## Complementing other methods

- Infrasound data can be integrated with observations from radar, cameras, and other sensors to create a more comprehensive picture of an asteroid impact, filling in gaps that other methods may miss

## Monitoring remote areas

- Infrasound sensors can be deployed in remote or hard-to-reach locations, providing coverage where traditional observation methods may be limited
- Infrasound sensors can operate day and night and in all weather conditions
- This expands our ability to monitor and study asteroid activity globally

# ENERGY DEPOSITION

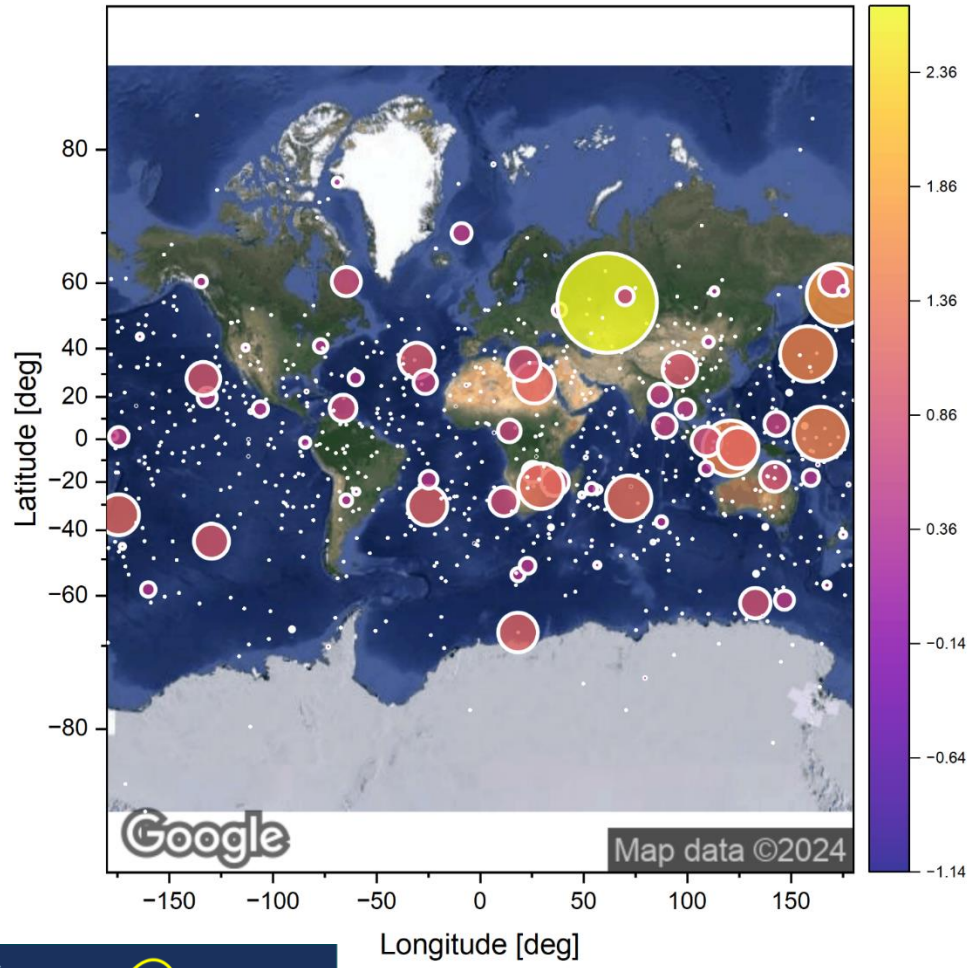
## What is the energy deposition of an asteroid?

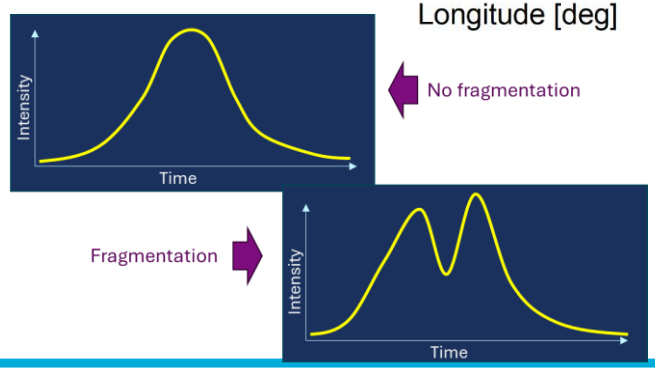
- Energy estimates typically come from space-based observations of light flashes (peak brightness)
  - US Government sensor data are published on the NASA JPL CNEOS webpage (~1000 events)
  - Data include valuable ground truth information
  - However, there are many more bolide events that are not reported on CNEOS, and we need a reliable means of estimating energy deposition
- Another approach uses infrasound signal period or amplitude and range to estimate energy
- Complication: empirical energy relations were initially established for other types of explosions and for stationary sources
  - Some of these relations have been used for estimating asteroid energy
  - Asteroids exhibit large variability in entry parameters

**Aim**: Constrain and refine energy estimates obtained through infrasound alone

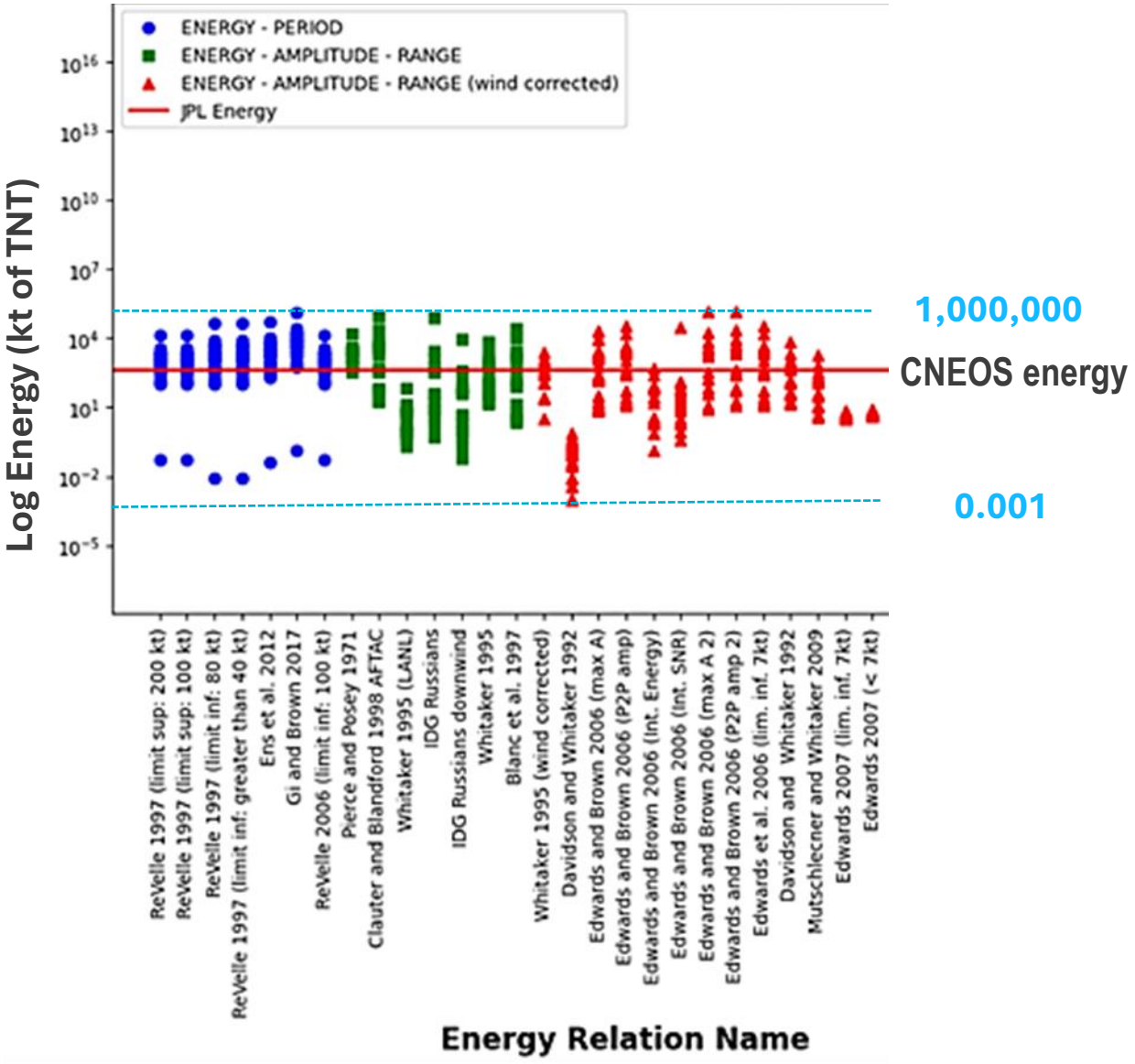
**Approach:** Integrate a number of parameters gathered through infrasound detections and space-based observations to account for and test large parameter space

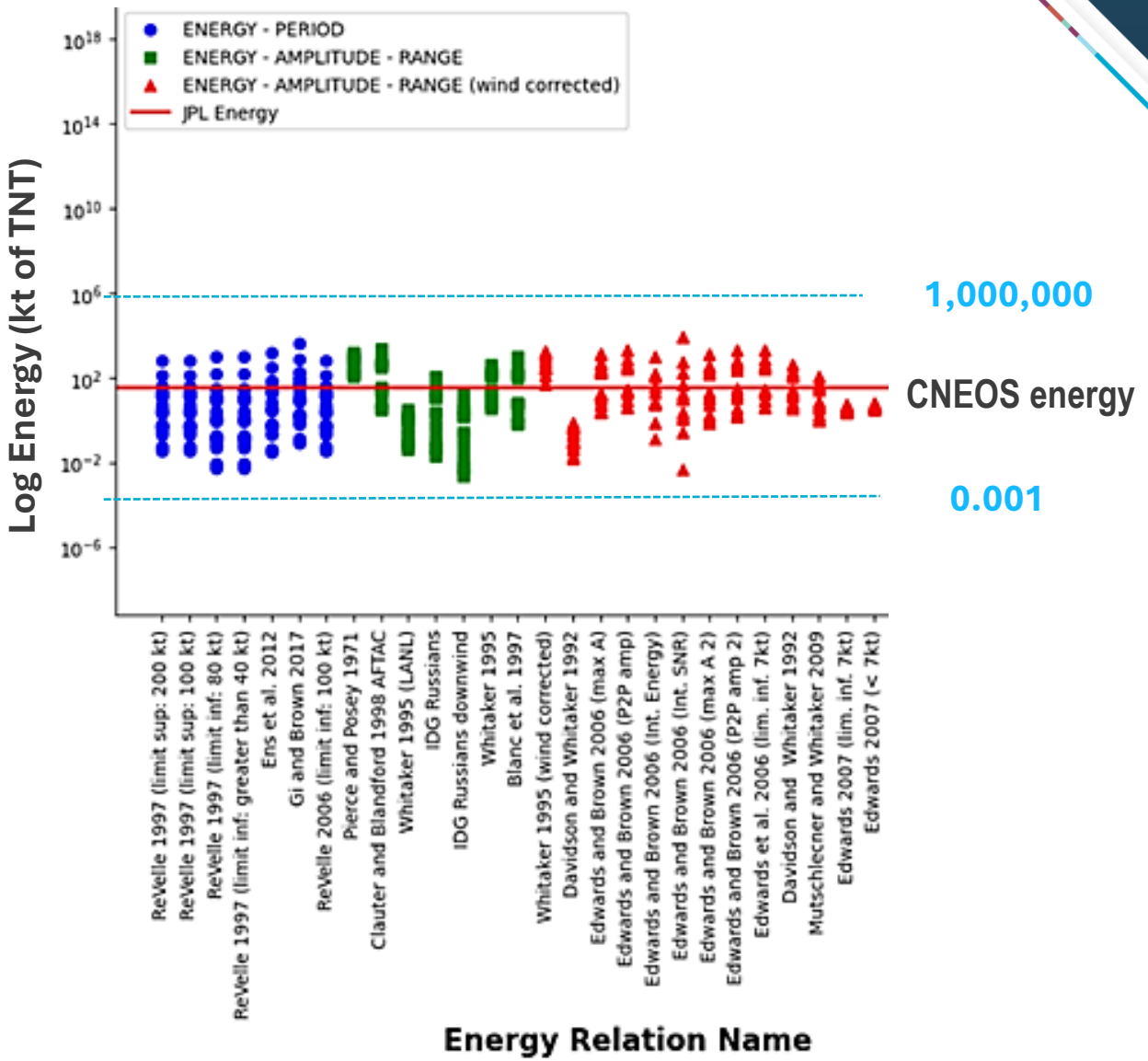
Figure from Silber, E. A. (2024). Perspectives and Challenges in Bolide Infrasound Processing and Interpretation: A Focused Review with Case Studies. Remote Sensing

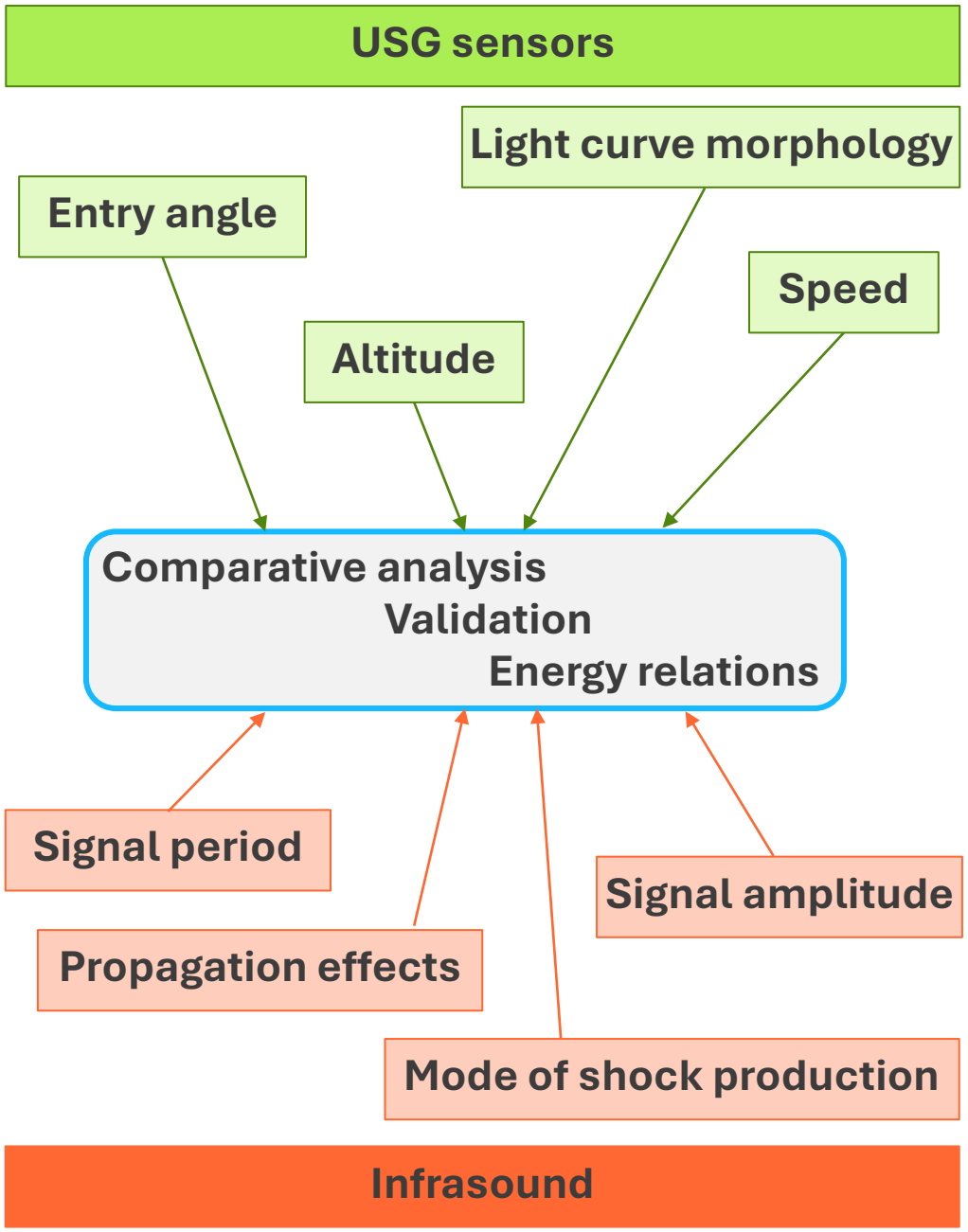


# ENERGY ESTIMATES THROUGH INFRASOUND






# MULTI-MODAL DETECTIONS TO ASSESS ENERGY RELATIONS

- We use a representative subset of bolides as case studies to conduct a comprehensive investigation
- Comparative analysis of signal parameters, physical characteristics and light curves
- Fragmentation / airburst vs. cylindrical line source (shock geometry is significantly different)
- Explore the fidelity and reliability of energy estimates obtained through acoustic sensing and compare infrasound-derived yield with the values published by CNEOS to develop a more holistic yet practical approach

## RELEVANCE TO PLANETARY DEFENSE

- Understanding the influx rates of objects ranging from meters to tens of meters in size
  - Can help better predict potential impacts
- Assessing the impact energy
  - Eventually leverage infrasound to estimate bolide size and velocity
- Critical for evaluating risks associated with different size classes
  - Advance our ability to monitor and respond to potential threats
- Identifying asteroid impacts over areas where other instruments have poor coverage
- Improved risk assessment and mitigation planning for asteroid impacts

## CONCLUDING REMARKS

- Detailed studies using multi-modal detections of asteroids can provide information (and model validation and refinement) that can be later used for events with limited ground truth
- Period-based energy relations are valuable, but we must also consider physical properties of bolides and infrasound characteristics for a complete analysis
- This holistic approach is crucial for advancing planetary defense strategies and improving our ability to estimate energy yield when only infrasound data are available

*Stay tuned for a publication!*

# RELEVANT PUBLICATIONS

- Physics of meteor generated shock waves in the Earth's atmosphere – A review
- An estimate of the terrestrial influx of large meteoroids from infrasonic measurements
- Infrasonic detection of a near-Earth object impact over Indonesia on 8 October 2009
- The Utility of Infrasound in Global Monitoring of Extraterrestrial Impacts: A Case Study of the 2008 July 23 Tajikistan Bolide
- Perspectives and Challenges in Bolide Infrasound Processing and Interpretation: A Focused Review with Case Studies
- Geophysical Observations of the 2023 September 24 OSIRIS-REx Sample Return Capsule Reentry
- Optical and acoustic ground effects simulations from terminal defense asteroid disruption via the PI method
- Asteroid disruption and deflection simulations for multi-modal planetary defense
- Elizabeth A. Silber Google Scholar page

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