Advances in Entry Modeling for Impact Risk Assessment

IAA Planetary Defense Conference
Vienna, Austria

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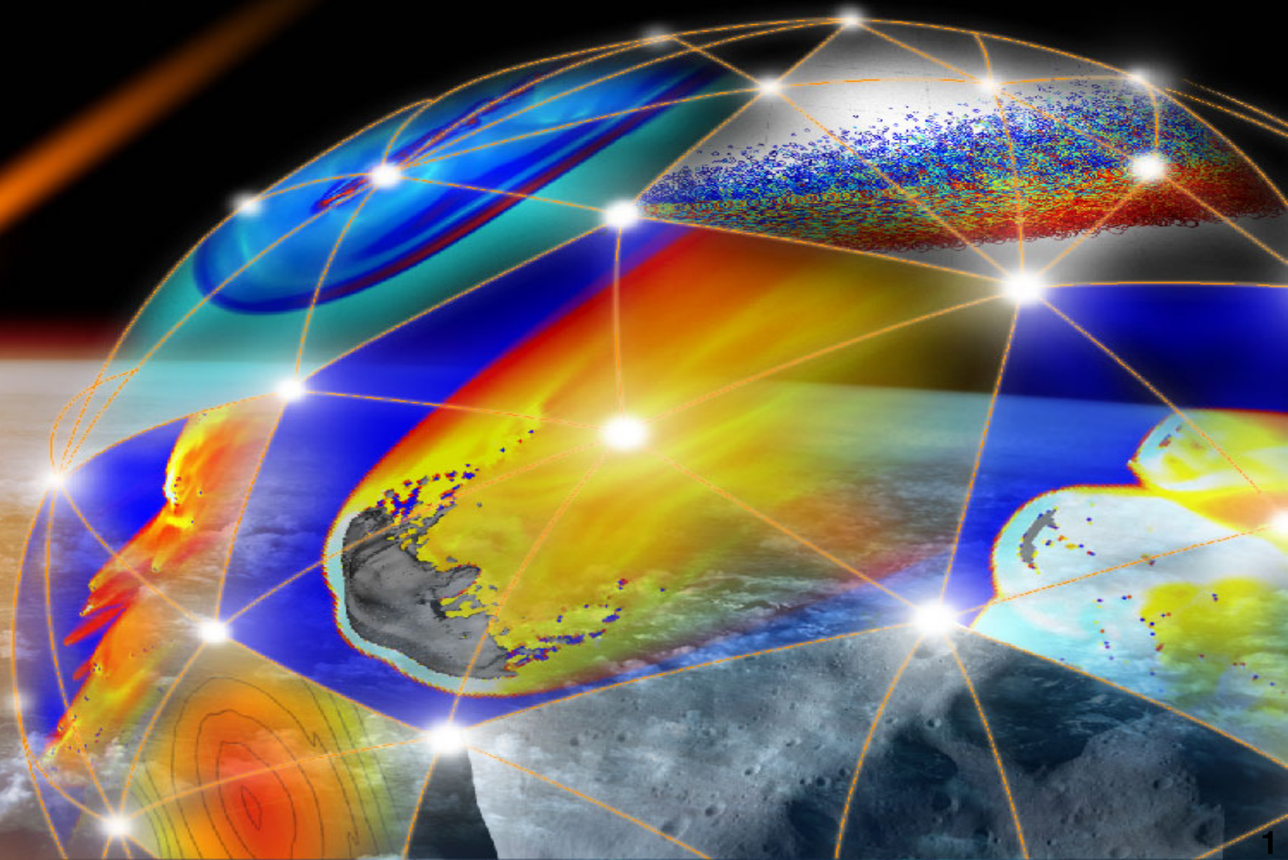
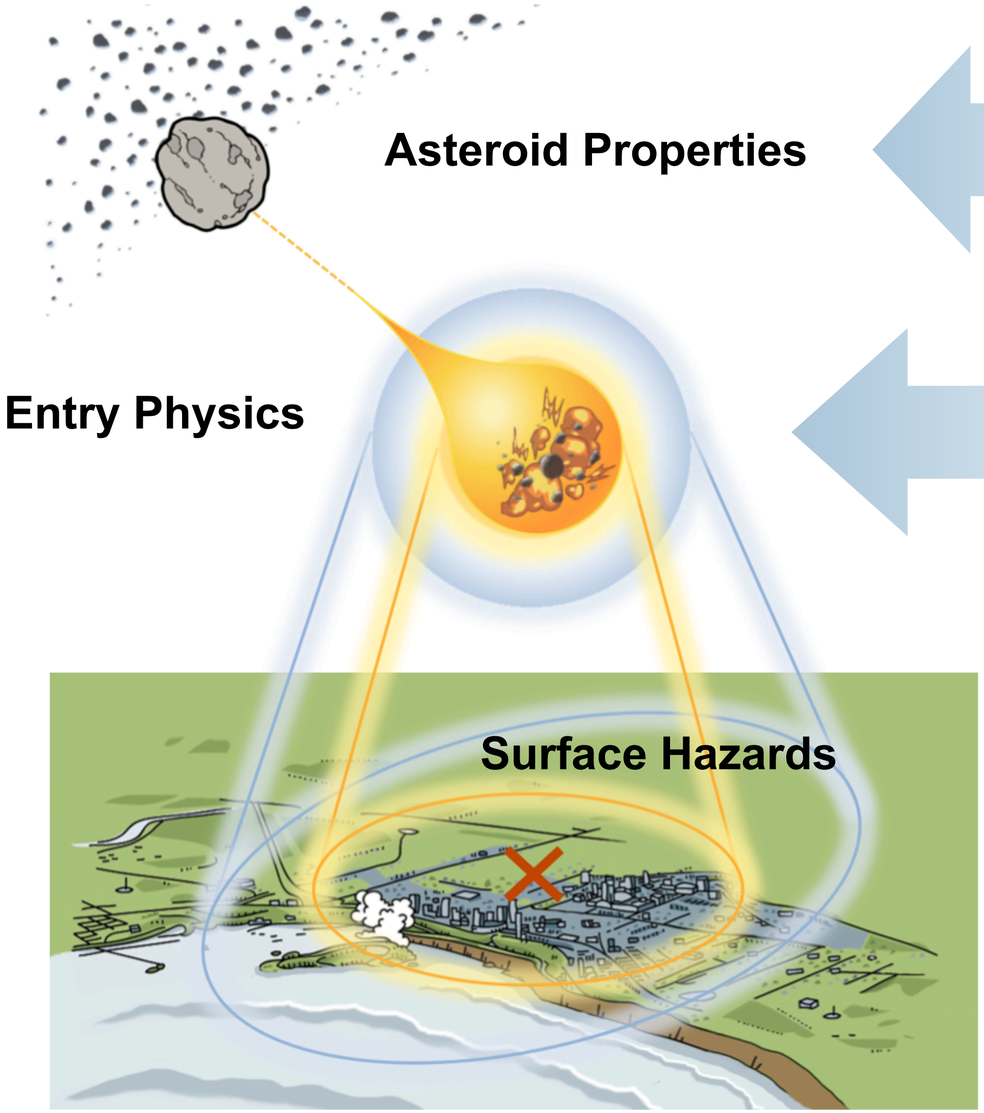


Asteroid Threat Assessment Project (ATAP)



Characterization
- Measurements
- Inference
- Data aggregation
- Property database website

Entry Simulations & Testing
- Flow modeling and radiation
- Ablation modeling and testing
- Fragmentation and break-up

Hazard Simulations
- 3D blast simulations
- Impact crater simulations
- Tsunami simulations
- Thermal radiation models
- Global effects

Probabilistic Risk Assessment
- Analytic physics-based entry and damage models
- Probabilistic Monte Carlo simulation using uncertainty distributions

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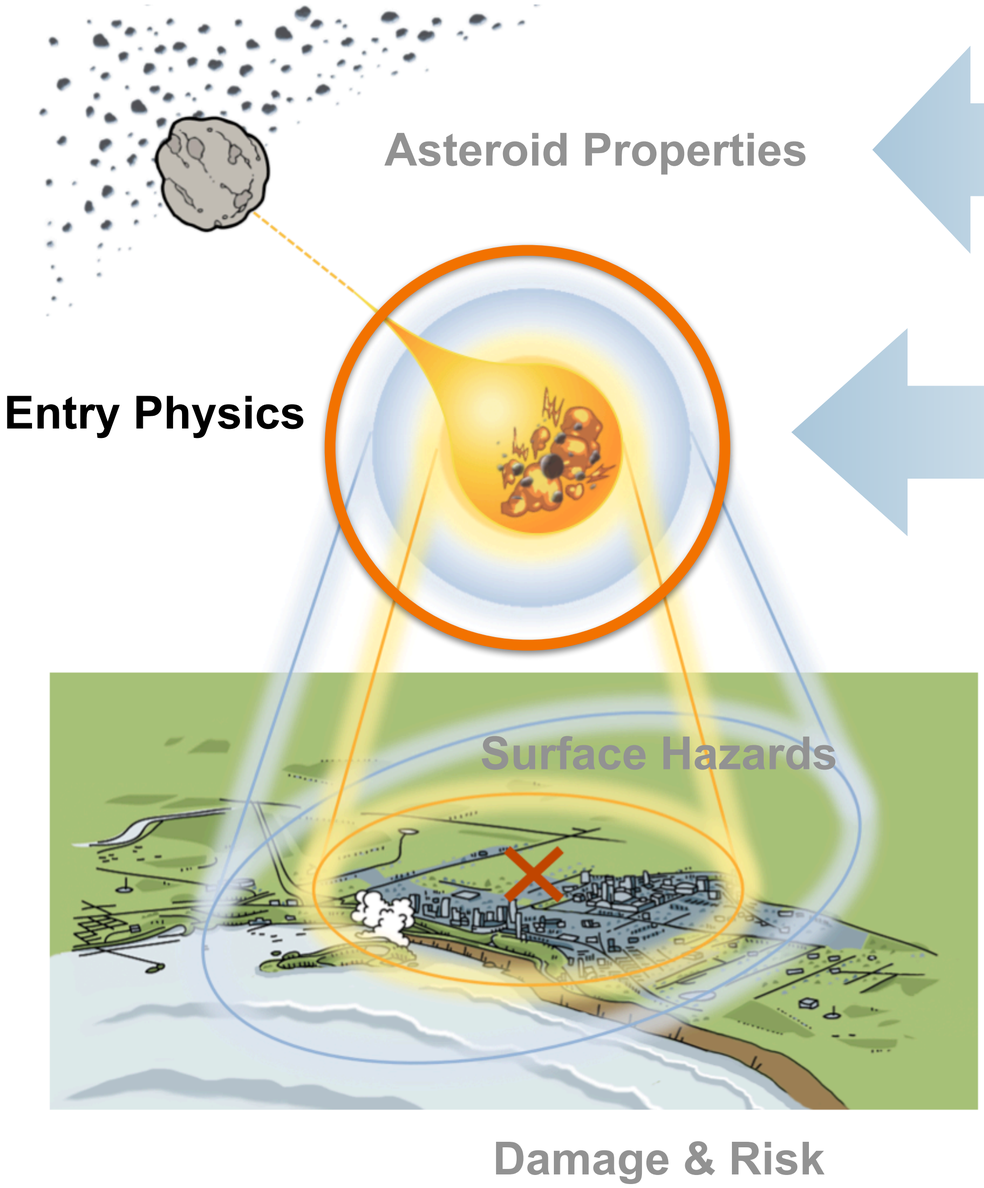

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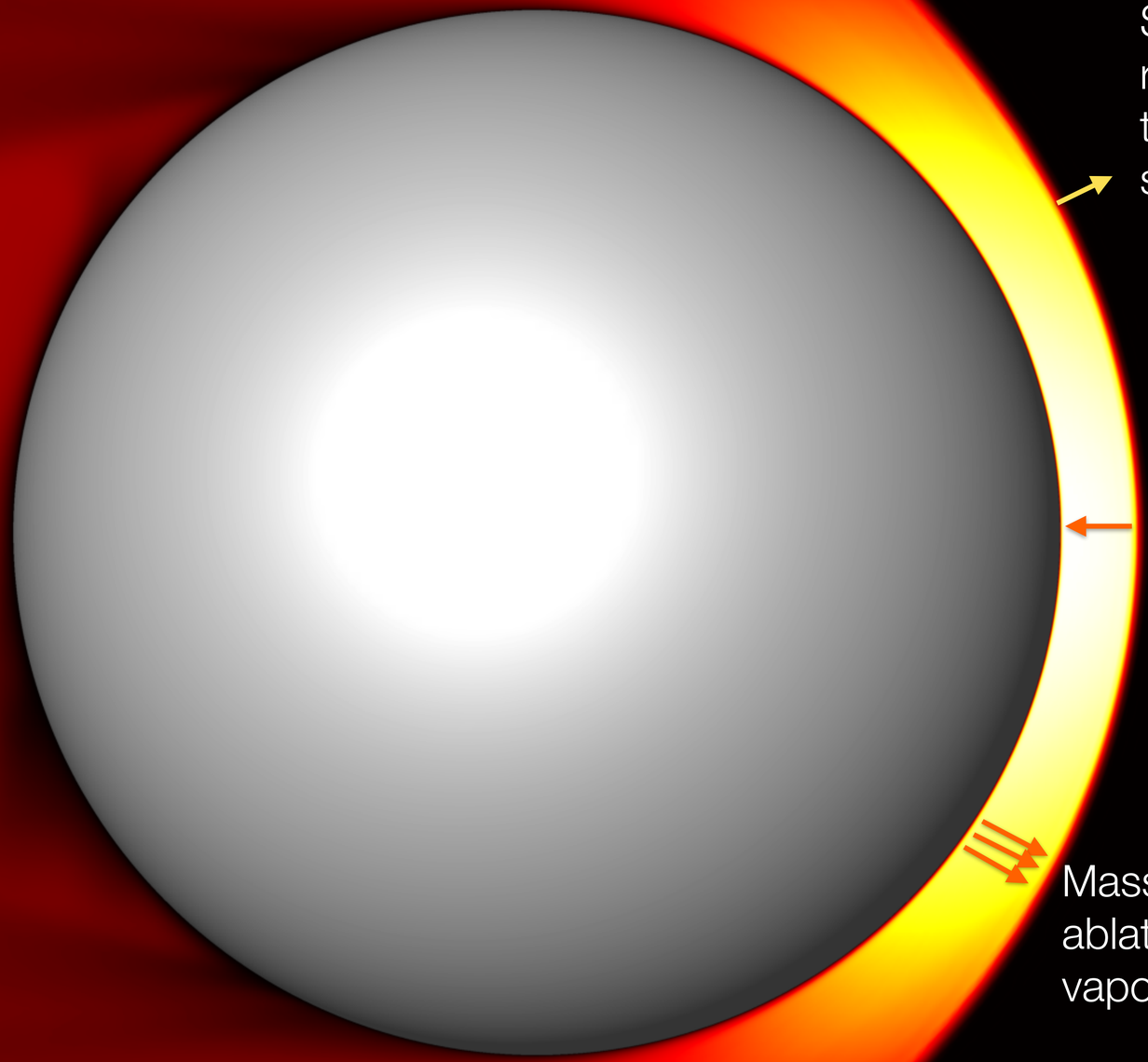
Entry Domain:

- Meteoroid itself
- Shock heated air
- Ablation products in the wake

Hazards:

- Blastwave propagation
- Thermal radiation
- Ground/water impacts

Flow Modeling and Radiation



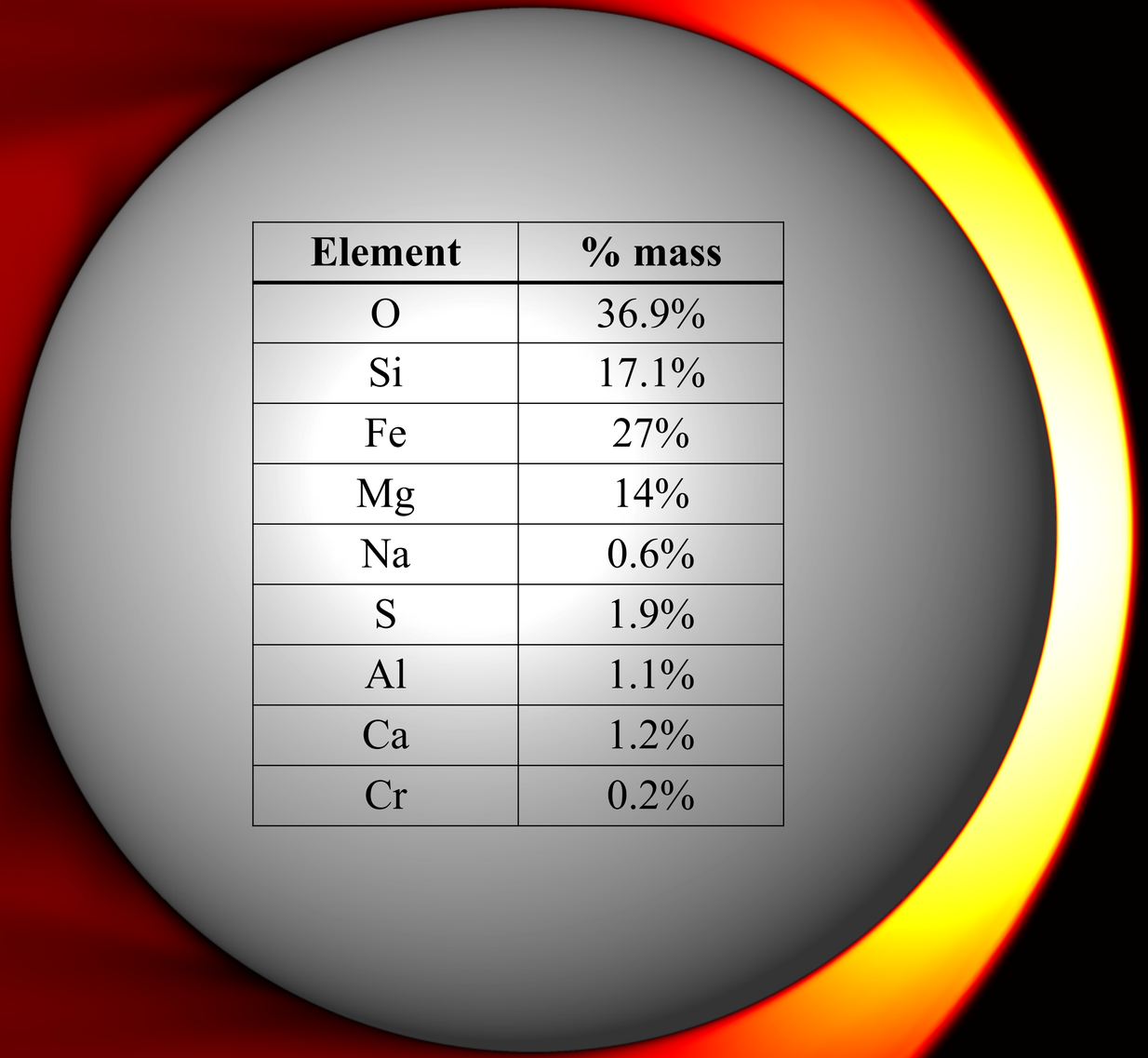
Shock layer radiates out to the surroundings

Extreme radiative heat flux to the surface

Massive ablation from vaporization

Heated ablation and high-temperature air species products radiation, producing observed light, spectra, and thermal radiation

Flow Modeling and Radiation



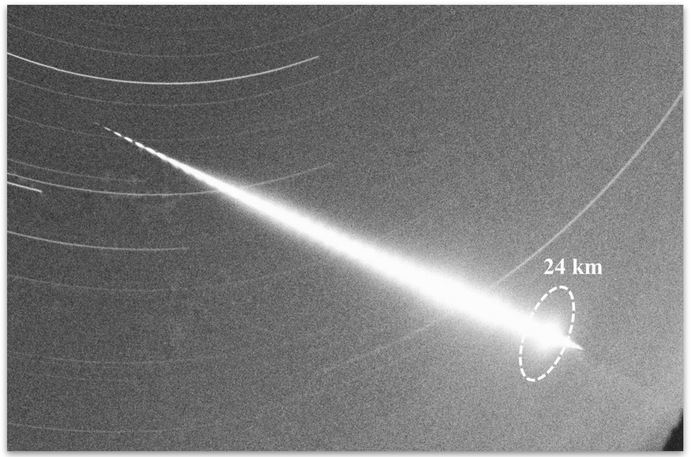
Element	% mass
O	36.9%
Si	17.1%
Fe	27%
Mg	14%
Na	0.6%
S	1.9%
Al	1.1%
Ca	1.2%
Cr	0.2%

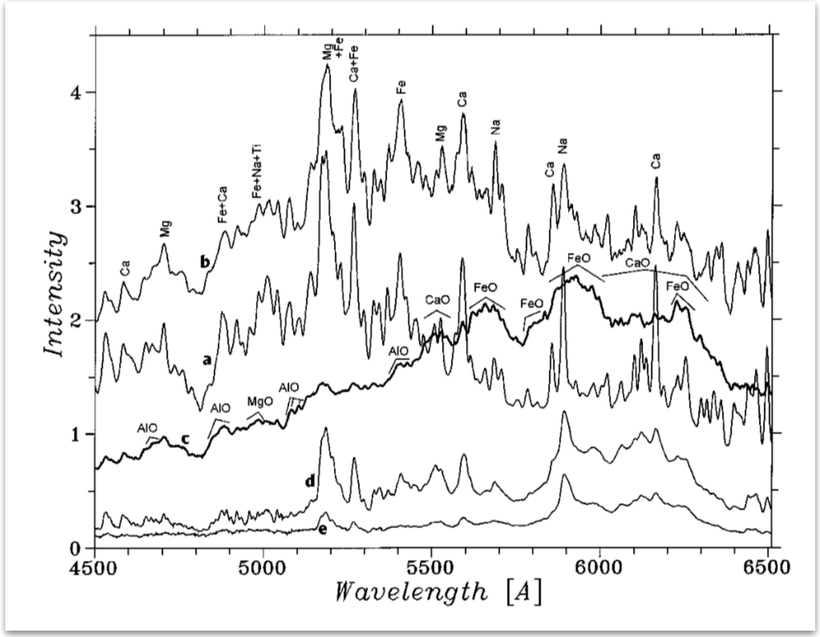
- LAURA hypersonic CFD code used for all simulations
- HARA radiation transport code is used to compute spectral radiance
- Vaporization of the meteoroid modeled using steady-state equilibrium assumption
- Melting not modeled
- Details on the computational approach can be found in Johnston et al., *Icarus*, 2018 & 2021

Benešov Validation Study

- Computational approach produces detailed spectra over an arbitrary wavelength range
- The Benešov bolide, which occurred over the Czech Republic on May 7, 1991, is one of the few meter class events for which detailed spectra were captured
  - ➡ Provides an invaluable source of validation data for entry models being applied to impact assessments

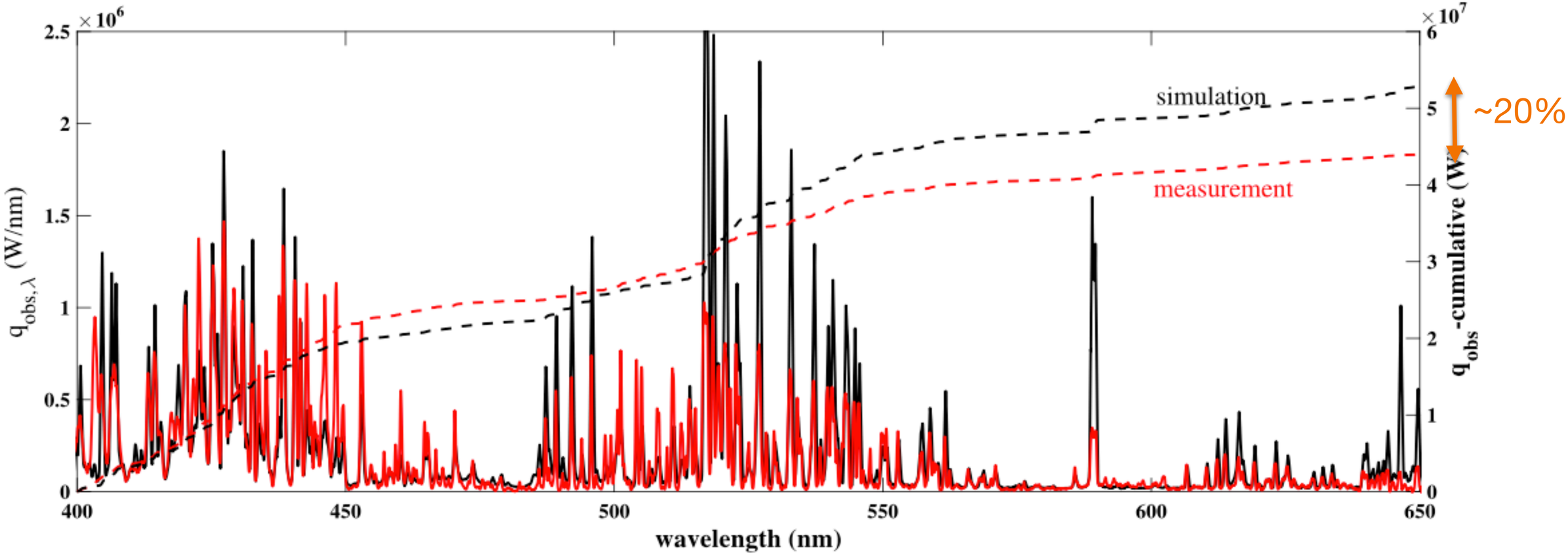
- Detailed computations were performed for a 0.8m sphere
  - ➡ Velocity = 20 km/s
  - ➡ Altitude = 47 and 57 km
  - ➡ LL chondrite elemental composition





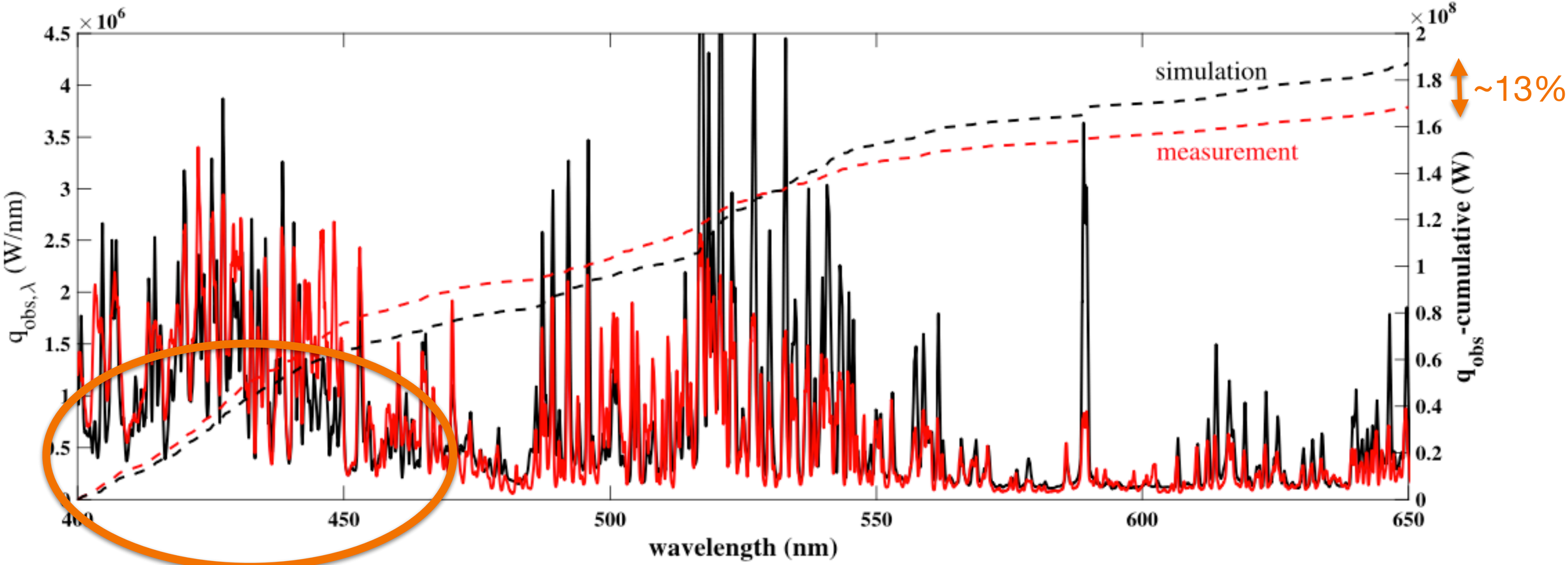
Borovička & Spurny, 1996

Benešov Spectrum at 57 km



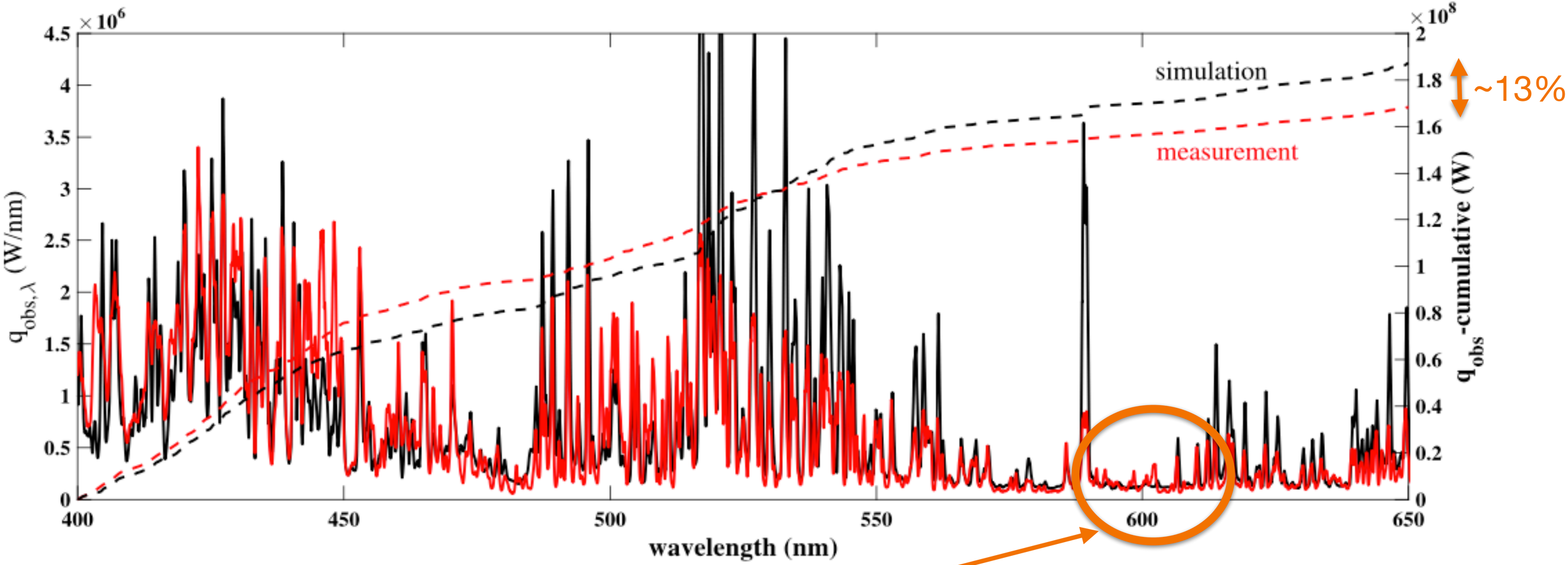
C. Johnston, E. Stern, J. Borovička, "Simulating the Benešov bolide flowfield and spectrum at altitudes of 47 and 57km," Icarus, 2021

Benešov Spectrum at 47km



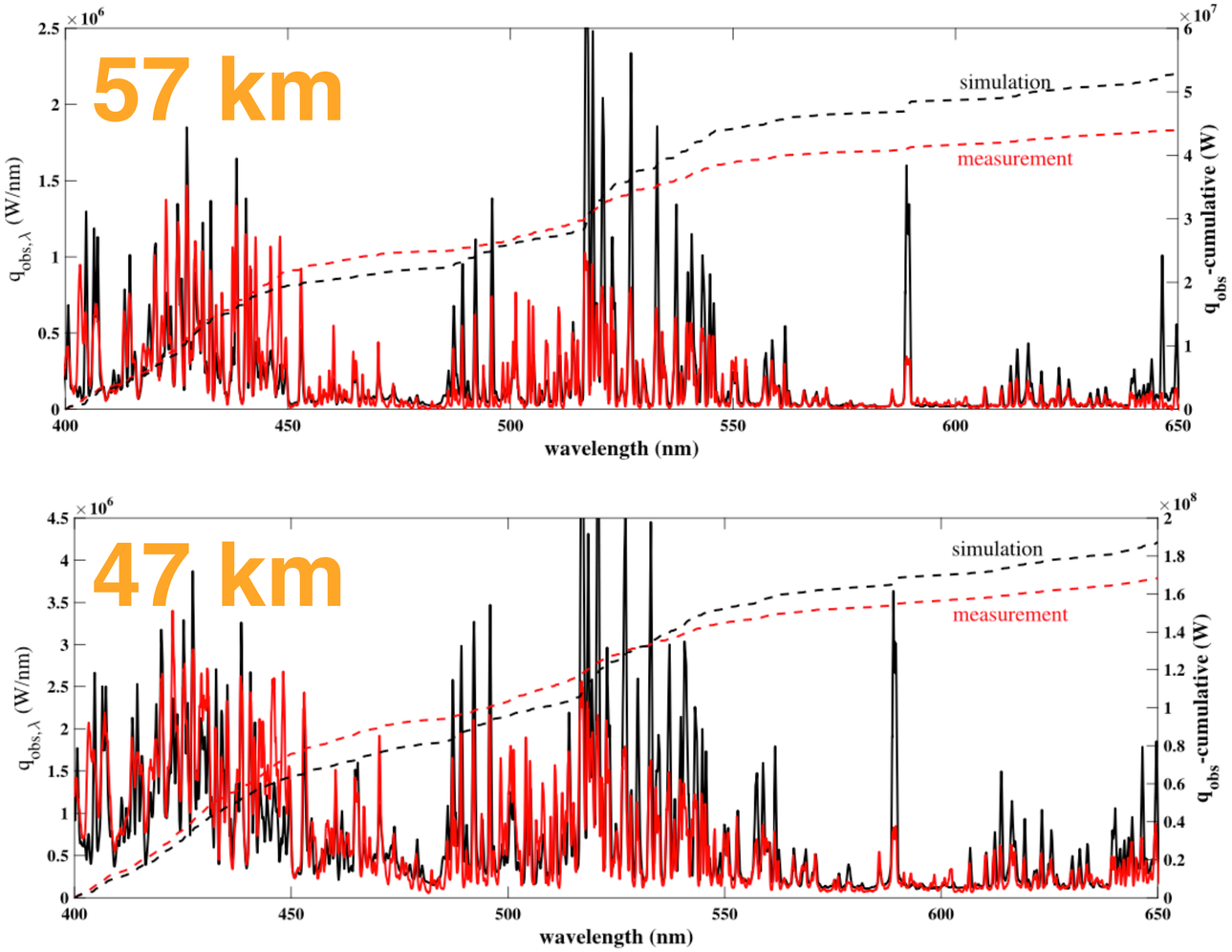
Increased contribution
from continuum radiation

Benešov Spectrum at 47km



Wavelength range dominated by bound-free transitions of air species → Better constrains meteoroid diameter

Benešov Study Findings



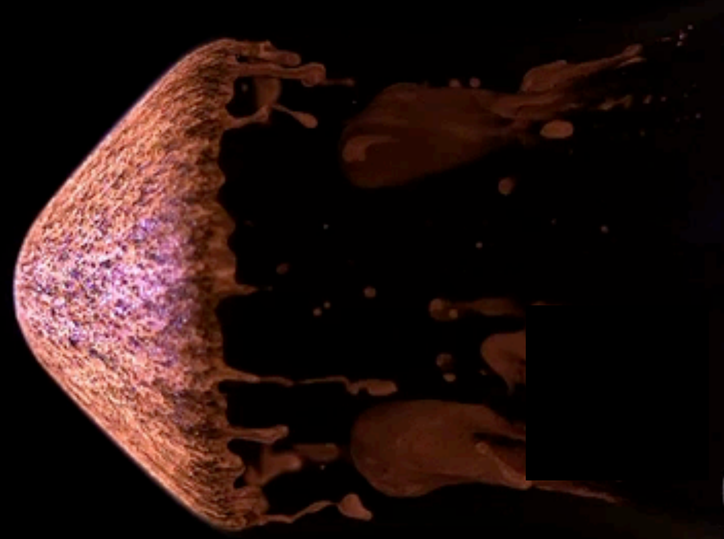
- Simulated spectra able to capture most of the significant spectral features from the observation
- For both altitudes simulated, the integrated luminosity from simulation is within 25% of observed spectrum

- Based on this analysis, we have confidence that our approach could be used to improve luminous efficiency models, and thus help to better constrain inferred asteroid properties

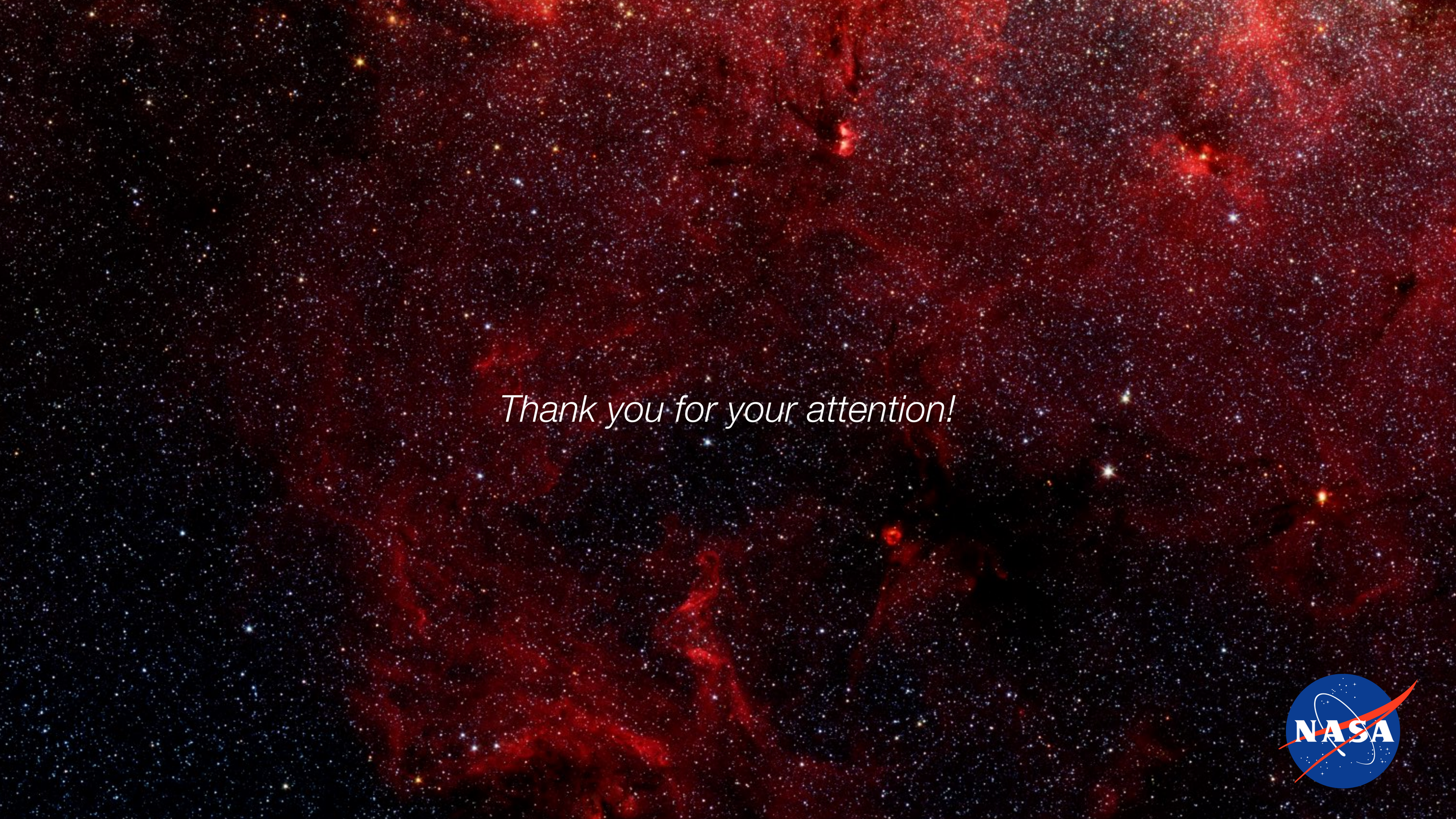
State-of-the-Art
(The good, the promising, and the ugly)

- **Flow Modeling and Radiation (“The Good”)**
  - “Tipping point” achieved in our predictive capability for radiation and luminosity
  - Modeling approach can now be applied to improving our reduced order models for meteoroid luminous efficiency
  - Can also be deployed in the design of future bolide observing campaigns

- **Ablation Modeling and Experiments (“The Promising”)**
  - Significant progress has been made on high-fidelity, first principles ablation models
  - Preliminary validation studies have been performed using high-enthalpy experiments



- **Fragmentation and Break-up (“…and the Ugly”)**
  - Remains the most challenging aspect of the asteroid entry problem
  - Tuned observational models, and nascent physics-based approaches do not converge
  - Current effort underway to utilize free-flight hypersonic wind tunnel experiments to aid in model development


Thank you for your attention!
NASA