Reduced Order Modeling for Non-equilibrium Radiation Hydrodynamics of Base Flow and Wakes: Enabling Manned Missions to Mars

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Research Objective:

- To **reduce predictive uncertainty** in the heating predictions for the back shell region, due to **CO_2 IR radiation**.
- Construct a computationally efficient physics/chemistry model for CFD that **is physics based** and **accurate** for Earth (10-16km/s) and Mars (5-8km/s) entries.
- Develop a new framework for the construction of **Coarse Grained Collisional and Radiative State To State model** to enable their application to current CFD models.
  - ***Time accurate, tight coupling*** between radiation and chemistry without relying on the QSS assumption.
- The starting **TRL is 1**, and the final is **TL is 3**.

Approach: *Coarse-Grain Method*

The methodology of reduction for **Collisional and Radiative STS** models consists of two distinct steps:

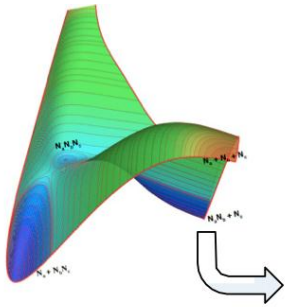
- **Local Representation and Reconstruction:** lumping of the internal energy levels in energy groups, and the reconstruction of population of each group, using macroscopic quantities.
- **Macroscopic Moment Equations and Rate Coefficients:** macroscopic governing equations are obtained by taking moments of the master equations.

Radiation and Kinetics Coupling

- **Operator Splitting Method:** enabling different grouping strategies for Radiation and Kinetics.
- **Semi-Implicit Time integration**

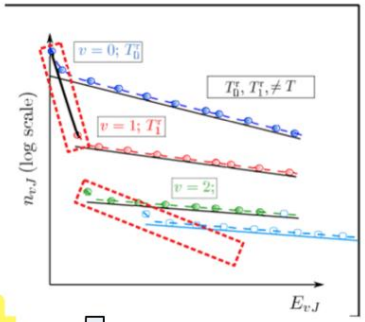
Validation/Calibration (EAST DATA)

- ***Bayes Inference:*** Calibration of the reduced model.



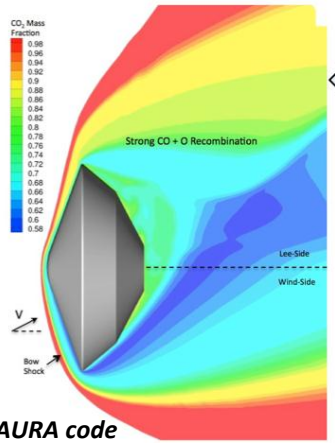
1. *Ab-initio Calculation of Kinetic parameters*

Develop a new model for Mars Chemistry and Radiation **CO** and ***CO_2 STS*** *Kinetics and Radiation*



2. *Coarse Graining CR-STS Model:*

*Grouping of ground and electronic excited states, **stochastic** and **deterministic** Master equation.*



Viking: LAURA code

3. *Application to CFD:*

Different Grouping strategies for radiation and kinetics.
US3D or LAURA.

4. *Calibration and Validation (V&V and UQ)*

Using EAST data, and Bayes inference

Potential Impact:

- **Predictive modeling** of strong non-equilibrium environments (Backshell).
- Modeling of Entry heating for ***all*** hypervelocity return missions such *as* ***OSIRIS-Rex and Insight*****, MAV, Lunar/Asteroid Sample Return & Crewed asteroid rendezvous.**
- **This innovative approach will transform the way non-equilibrium flows can be understood and modeled by the community.**