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ADVANCED CHARACTERIZATION OF PARTICULATE FLOWS FOR CONCENTRATING SOLAR POWER APPLICATIONS

GEN3 CSP SUMMIT 2021

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CREATING THE NEXT®

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Determination of intrinsic heat transfer and flow properties over a range of temperatures and particle types and sizes

- Determination of fundamental radiative heat transfer properties
- Determination of properties for the particle bed
- Determination of fundamental mechanical properties related to particulate flow

Heat transfer modeling and validation

- Heat transfer modeling coupling flow and heat transfer properties
- A range of flow experiments at temperatures without and with high-flux solar irradiation

Flow characterization and modeling (LIGGGHTS) for different flows, particles, and temperatures

PROJECT OUTCOMES

Accessible database/publications containing "first of their kind" results related to particulate flows as tools to catalyze next generation solar particle heat receivers/reactors:

- Intrinsic radiative heat transfer and flow properties for granular flows for a range of particles
- Granular flow experiments and models
- Simple to complex experiments for a range of particles, temperatures, and flow configurations: Inclined flow → vertical flow between parallel plates → stairstep flow → flow exposed to high radiative fluxes (high-flux solar simulator)
- Validated heat and mass transfer models

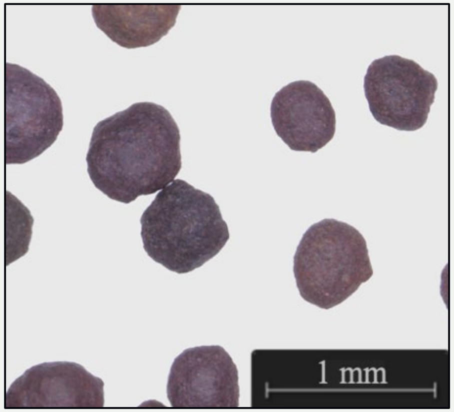
PARTICLES CHARACTERIZED

Carbobead CP

Carbo HSP

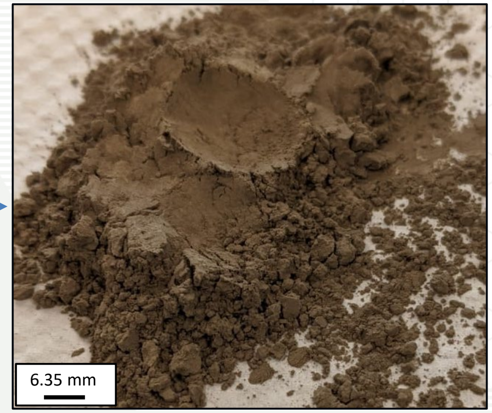
Wedron SiO_2

PARTICLE PREPARATION



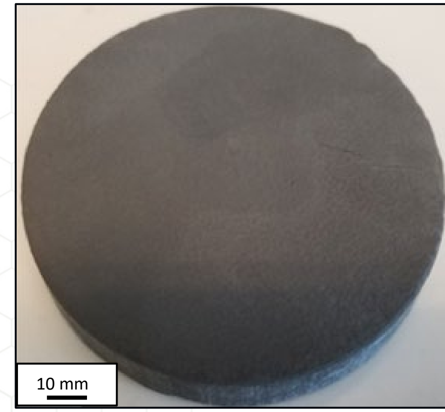
Particles

Jet-mill



Flour

Hot-press



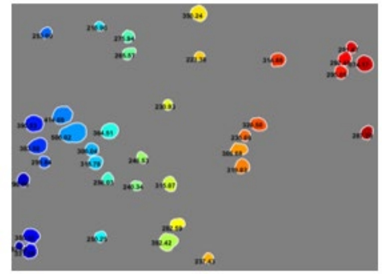
Hot-pressed plate

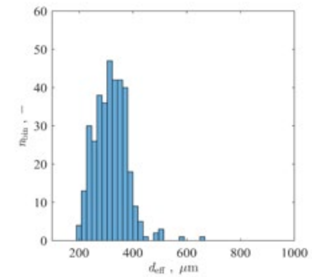
Machine

Specimens of different geometries

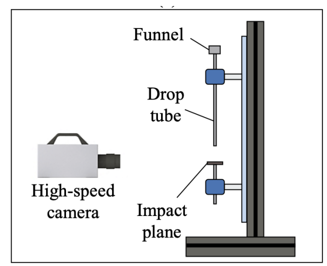
- Intrinsic properties measured using hot-pressed, machined plates
  - Elastic properties
  - Sliding/rolling surface for friction coefficients
  - Impact plane for coefficient of restitution
- Flour for Carbo HSP jet-milled with collaboration with SNL
- Silica flour obtained from NREL

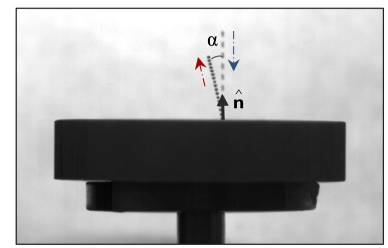
Developed a program to determine particle size distributions and roundness



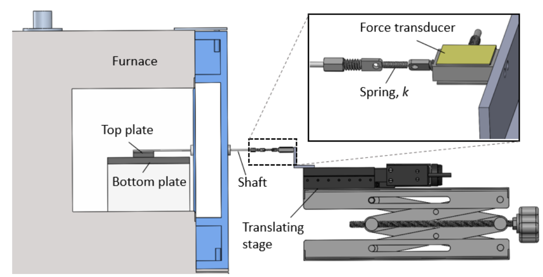


Particle drop setup coupled to a high-speed camera to measure coefficient of restitution





Used a slip stick method mounted in a high-temperature furnace to measure static and rolling friction

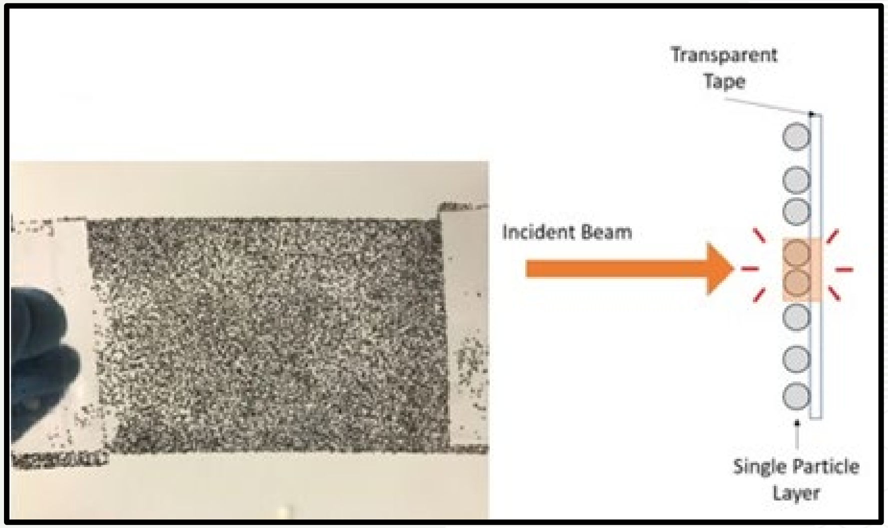


Determined elastic and shear moduli using impulse excitation for different temperatures

RADIATIVE PROPERTY DETERMINATION TO DETERMINE VOLUME-AVERAGED PROPERTIES

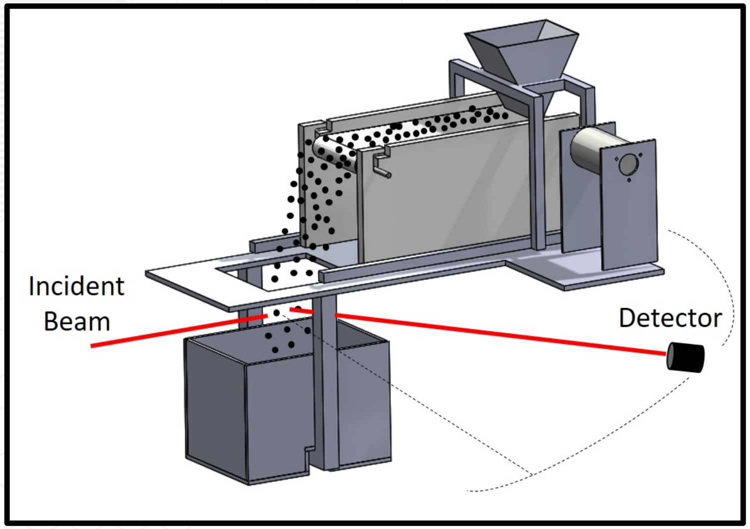
Particle tape method

- More stable method due to constant areal fraction throughout the measuring period.
- Additional factors (*e.g.*, scattering and absorption by the tape) need to be accounted for the analysis.
- Pure scattering data of the particle can be obtained by subtracting the scattering measurement of tape.



Particle curtain method

- A direct way to obtain scattering property without introducing other measurement uncertainties.
- Flowing nature of the particles makes the measured signal unstable and long sampling period is required.



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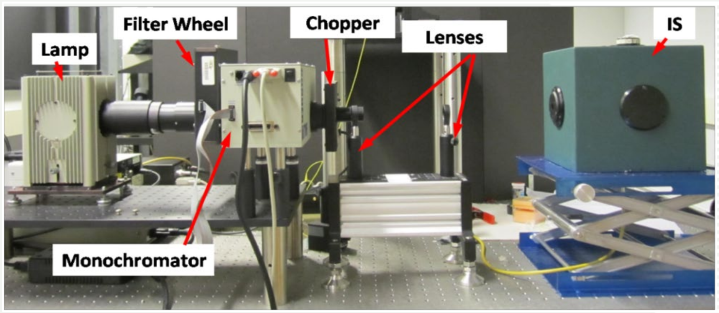
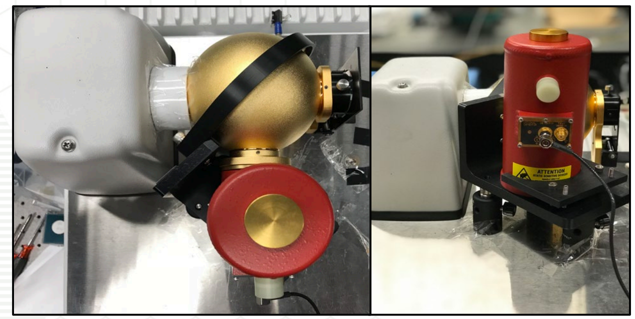
Monochromator with Integrating Sphere

- Quartz window sample holder
- 0.38-1.8 μm



FTIR with Integrating Sphere

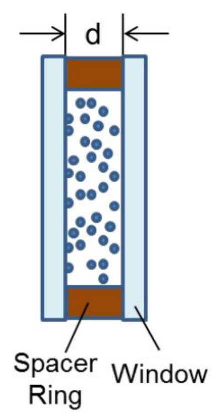
- ZnSe window sample holder
- 1.8-16 μm

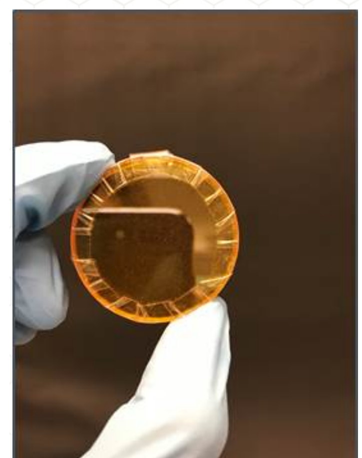


Sample Holder Design

Quartz Window Sample Holder

Particle Beds
Various thicknesses
Cover plates
Thickness = 1.6 mm

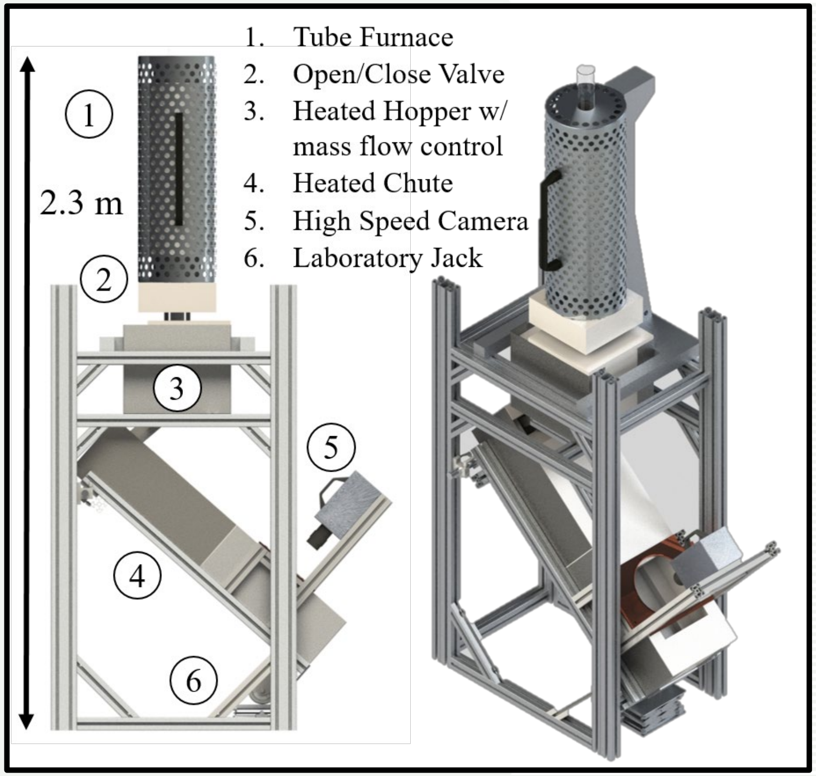




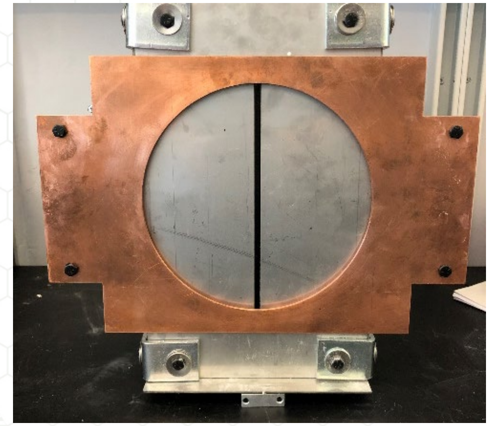
ZnSe Window Sample Holder

Particle Bed
Thickness = 6.35 mm
Cover plates Thickness = 3.0 mm

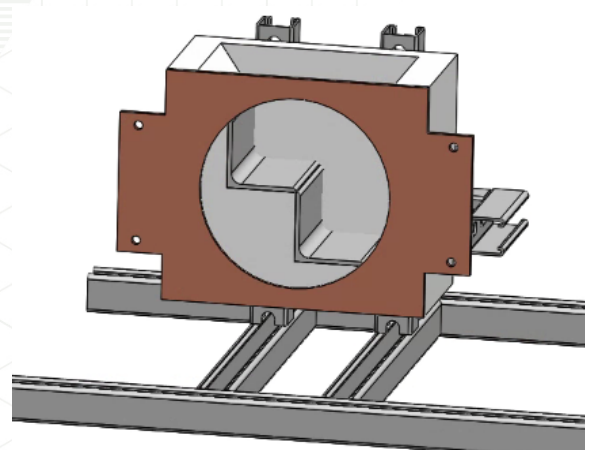
TILT FLOW RIG



Solid works rendering of modified inclined-flow experimental rig with important features labeled and viewed from various angles



Vertical plate flow setup



Design of stair-step flow geometry

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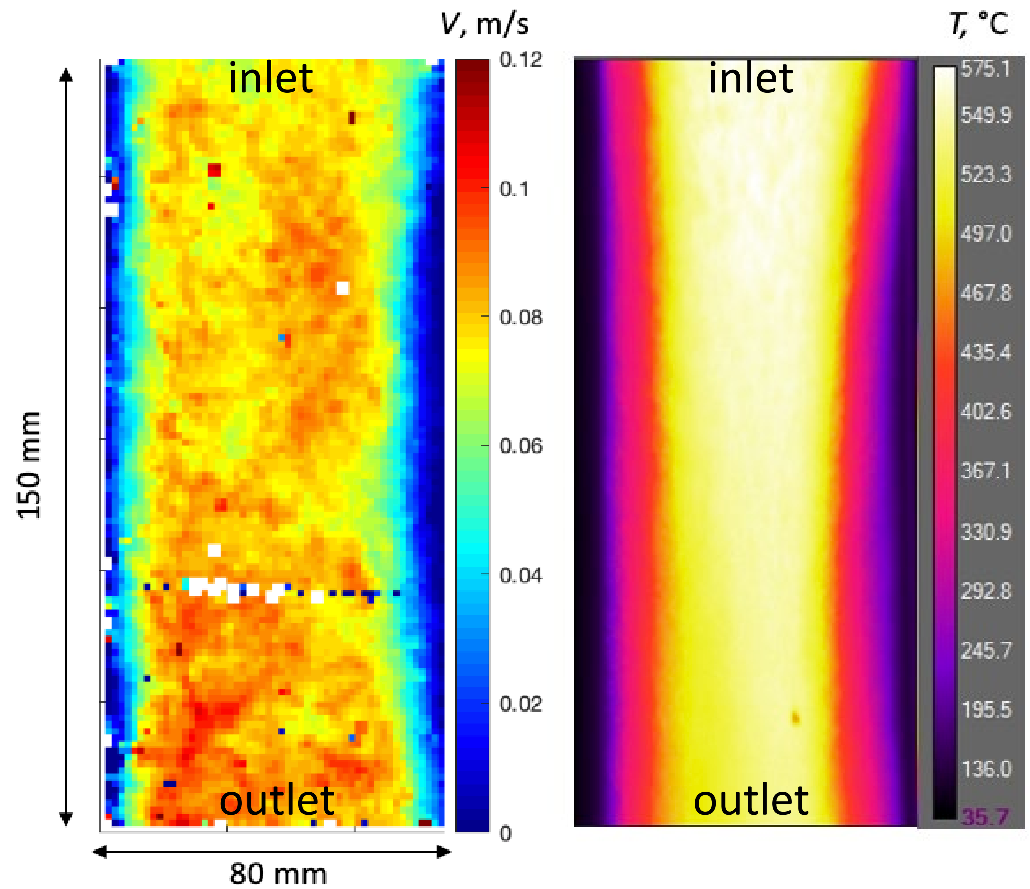
- Experiment performed using Carbobead CP 30/60
- Particles heated to 600 °C in tube furnace and released onto inclined plane (27° inclination)
- Bulk surface V_{inlet} = ~0.07 m/s, V_{outlet} = ~0.09 m/s
- Bulk surface T_{inlet} = ~560 °C , T_{outlet} = ~525 °C
- Boundary conditions from experiment to be incorporated in flow and heat transfer models



Free-surface velocities **Free-surface temperatures**

SUMMARY AND CONCLUSIONS

- Our project has focused on addressing a **significant** gap related to granular flows at elevated temperatures.
- Radiative heat transfer properties have been measured to determine volume-averaged extinction and scattering coefficients for different flows to inform heat transfer modeling
- Flow properties coupled to experimentation at elevated temperatures for a range of flow configurations and modeling granular flows and heat transfer have highlighted the impact of temperature on these flows with strong evidence that this must be considered in the design of solar particle heating receivers/reactors and related flow infrastructure
- Our updated database and publications of our work outline these changes and provide a basis for the design of the next generation of CSP coupled to particle-based thermal energy storage
    - http://hdl.handle.net/1853/62903
    - http://hdl.handle.net/1853/63725
    - We have a dropbox with preliminary results that may be made available

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HIGH-FLUX SOLAR SIMULATOR

- Seven 6 kW_e xenon arc lamps
- Mounted in truncated ellipsoidal reflectors
- Capable of focusing intense irradiation (*i.e.,*~5000 $kW \cdot m^{-2}$) over a 40 mm diameter with a similar spectral distribution as the sun
- Allows for reproducible experimentation and the inputs can be varied by varying lamp power

HIGH-TEMPERATURE EMISSOMETER

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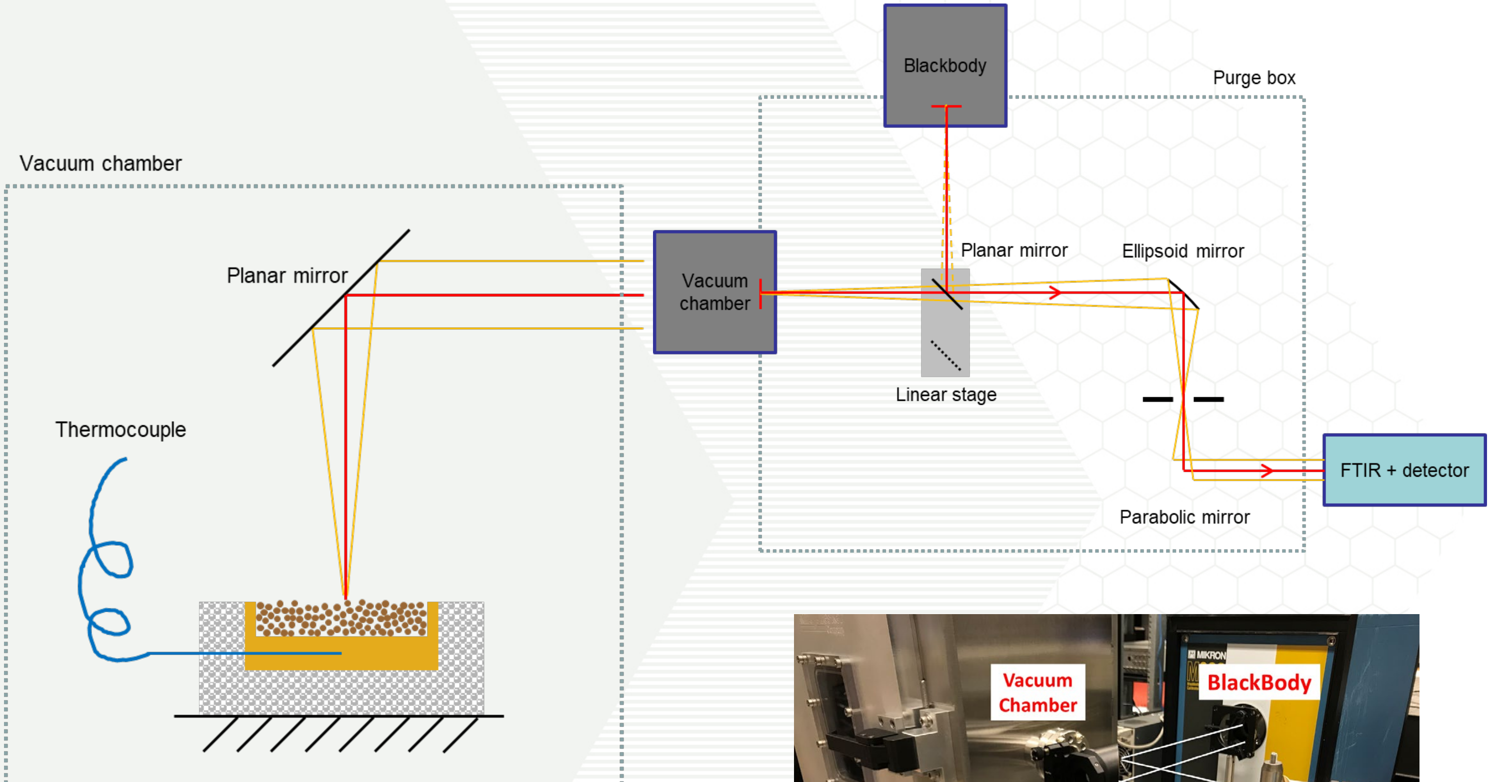

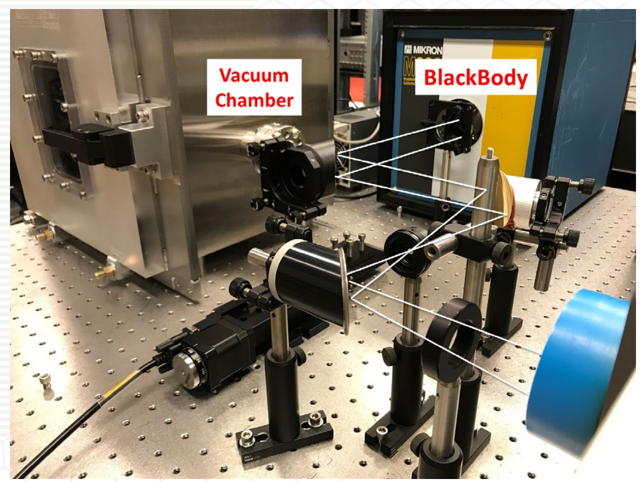

- Up to 750 °C
- Near normal emittance of particle beds
- 2 – 16 mm.