National Aeronautics and
Space Administration

Advanced Combustion via Microgravity Experiments (ACME) on the International Space Station (ISS)

Laminar spherical and axisymmetric nonpremixed flames of gaseous fuels.

Fundamental research focused primarily on practical terrestrial combustion, but also spacecraft fire safety.

Six independent experiments using one set of modular hardware.

Five studies selected by NASA. One study selected by NSF (National Science Foundation) and CASIS (Center for the Advancement of Science in Space).

U.S.-led research in collaboration with Russian universities
- Far Eastern Federal University
- Peter the Great St. Petersburg Polytechnic University

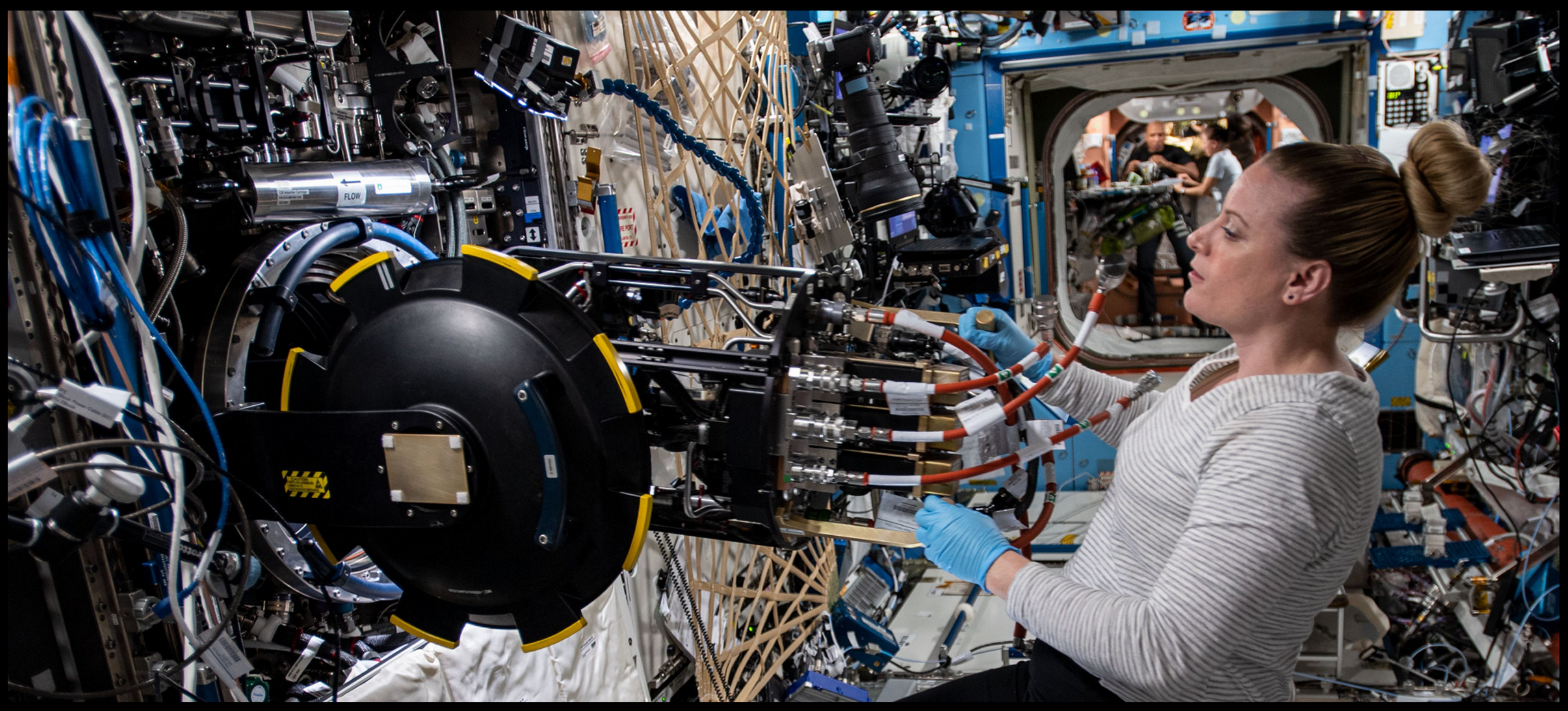
and institutes of the Russian Academy of Sciences
- N.N. Semenov Institute of Chemical Physics
- P.N. Lebedev Physical Institute

Tests carried out within the Combustion Integrated Rack (CIR).

Hardware set up by ISS crew members from Canada, Germany, Italy, Japan, Russia, and the United States.

Tests remotely commanded from NASA's Glenn ISS Payload Operations Center.

Four CIR ground consoles staffed during test operations.



On-orbit operations underway since September 2017.

Over 1,000 flames ignited during 3.5 years of ISS testing.

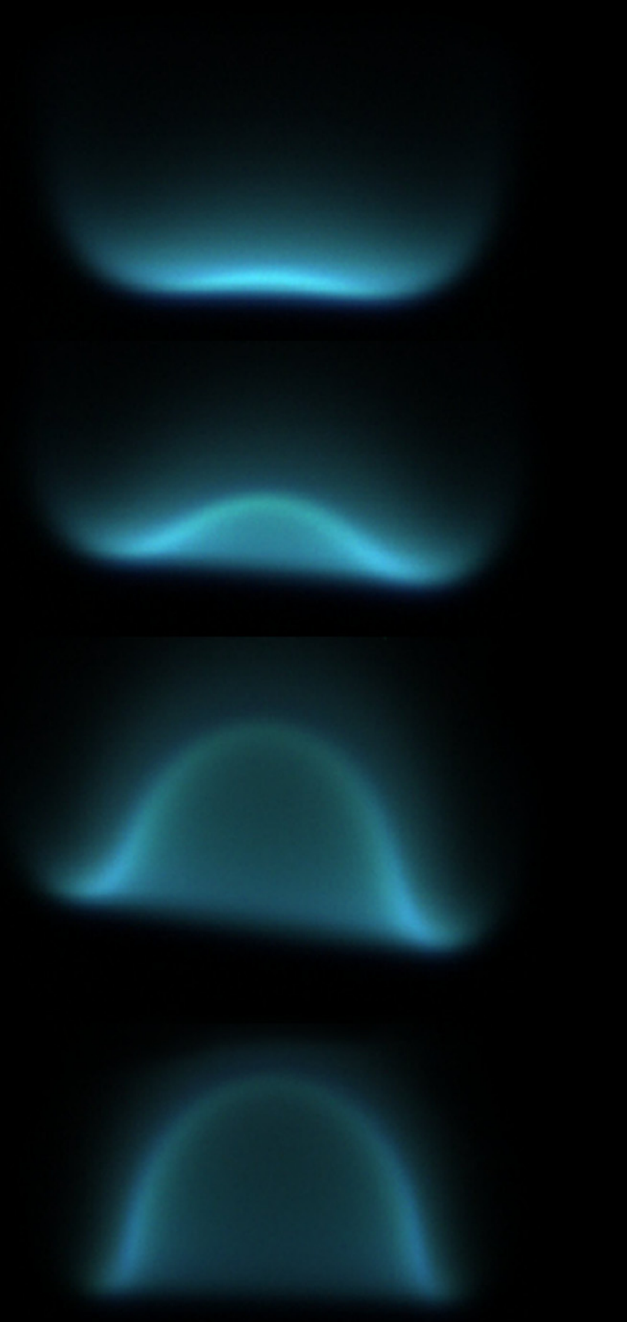
Space station tests for four of six ACME experiments completed.

Open-source data gradually shared via www.nasa.gov/PSI. NASA periodically offers funding opportunities for its analysis.

Engineering and operations by ZIN Technologies, Inc.

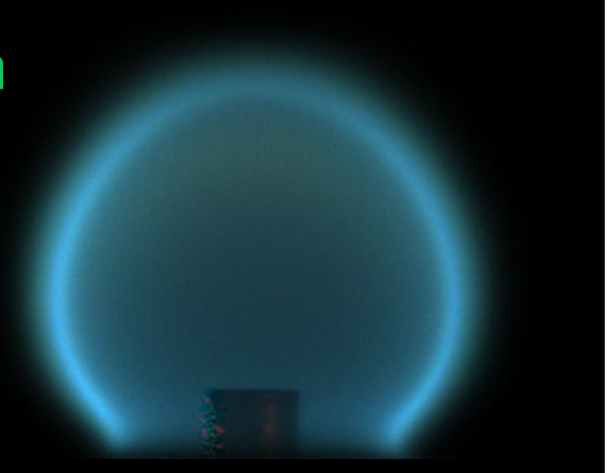
Managed by NASA's Glenn Research Center in Cleveland, Ohio.

Coflow Laminar Diffusion Flame (CLD Flame)



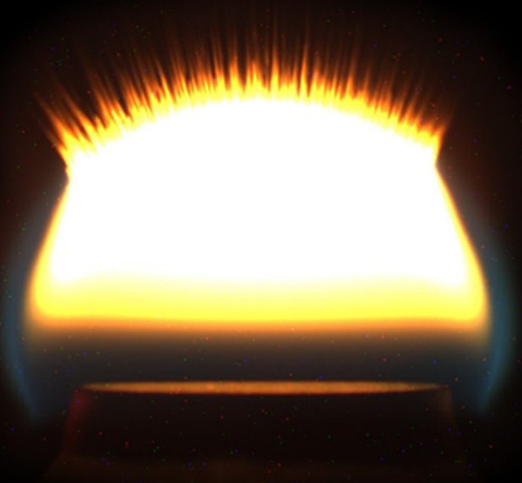
- Key researchers: Marshall Long, Mitch Smooke, and Jesse Tinajero (Yale)
- Goal: Improve computational flame models with benchmark quantitative data for sooty and extremely diluted microgravity flames.
- Selected findings
  - Microgravity flames contain five to eight times more soot than the equivalent normal-gravity flames.
  - Microgravity flames are taller and wider.
  - Microgravity increases the limits of fuel dilution for both methane and ethylene flames. Near limits, microgravity flames are more stable, allowing for lifted flames at lower fuel concentrations.

Electric-Field Effects on Laminar Diffusion Flames (E-FIELD Flames)



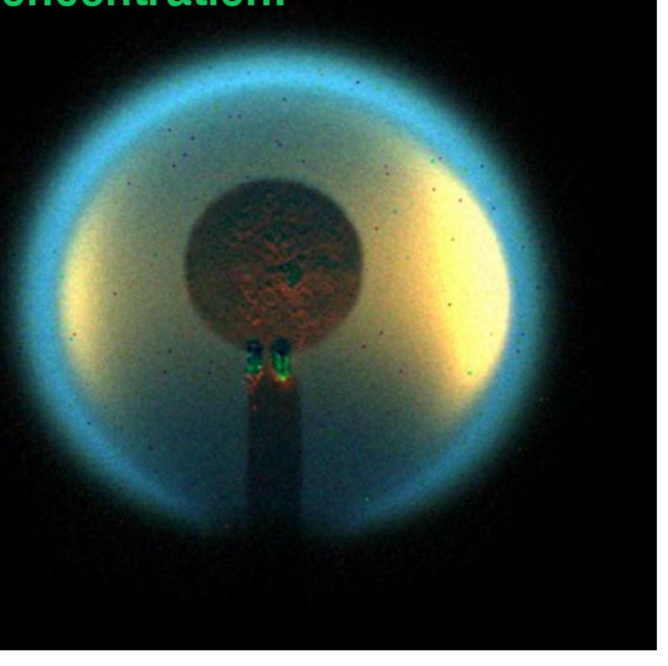
- Key researchers: Derek Dunn-Rankin and Yu-Chien Chien (UC Irvine)
- Goal: Understand chemi-ionization in flames and the interplay between ion generation and ion-driven flows.
- Selected findings
  - In microgravity, flames exhibit a distinct peak ion current that corresponds to the most compact flame.
  - There are clear correlations between flame luminosity, combustion intensity, and ion current.
  - When soot is present in a flame, electric fields create a wide range of behaviors.
  - Highly diluted flames can be stabilized with very weak electric fields.
  - Jet flames, under the influence of the electric field, were unstable at high field strengths and exhibited corona and then arc discharges.

Burning Rate Emulator (BRE)



- Key researchers: Jim Quintiere and Peter Sunderland (U. Maryland), and John de Ris (FM Global, retired)
- Goal: Determine burning conditions in still atmospheres as a function of material properties.
- Selected findings
  - Low-momentum microgravity flames can burn for minutes in the absence of an airflow or flame spread.
  - While the flames can burn for minutes in elevated oxygen concentrations, like those being considered for future spacecraft, they were found to self-extinguish in concentrations below ~25 percent (by volume).
  - While smaller flames can burn for minutes at elevated oxygen concentrations, larger flames were generally seen to self-extinguish within 1.5 minutes.
  - While ethylene flames at elevated oxygen concentrations can burn for minutes, methane flames were seen to self-extinguish within a minute.

Flame Design



- Key researchers: Rich Axelbaum (Washington U. in St. Louis) and Peter Sunderland (U. Maryland)
- Goal: Improve understanding of soot inception and control to enable the optimization of oxygen-enriched combustion and the "design" of nonpremixed flames that are both robust and soot free.
- Selected findings
  - Flame size increases with reactant flow rate and decreases with ambient oxygen concentration.
  - Very small flames have low radiative loss and asymptotically approach steady-state behavior.
  - Large flames increase in size over time until the flame extinguishes due to radiative heat loss.
  - Before total extinction, these flames experience an unstable, oscillatory mode, in which they partially extinguish and reform. The oscillations grow in magnitude until total extinction.

Structure and Response of Spherical Diffusion Flames (s-Flame)

- Key researchers: C.K. Law (Princeton) and Stephen Tse (Rutgers)
- Goal: Characterize and gain predictive capability of spherical diffusion flames; interrogate and possibly modify chemical kinetic mechanisms and transport submodels.
- Selected findings
  - Both radiative and kinetic (i.e., convective) extinction of the spherical flames appear to have been observed.
  - Radiative extinction seems to occur at high flow rates and kinetic extinction at low flow rates. The latter may seem counterintuitive, but at low flow rates, the flames are close to the burner where the velocities are highest.
  - With helium, rather than nitrogen, dilution of both the fuel and oxygen, the extinction limits are shifted and kinetic extinction is generally difficult to discern.

Cool Flames Investigation with Gases (CFI-G)

- Key researchers: Peter Sunderland (U. Maryland), Rich Axelbaum (Washington U. in St. Louis), and Forman Williams (UC San Diego)
- Goal: Observe quasi-steady nonpremixed spherical cool flames.

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