

# **U.S. AIR FORCE BASIC RESEARCH IN WEAKLY IONIZED GASDYNAMICS**

**21-25 June 2004**



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AFOSR/NA**

**Air Force Research Laboratory**

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# Report Documentation Page

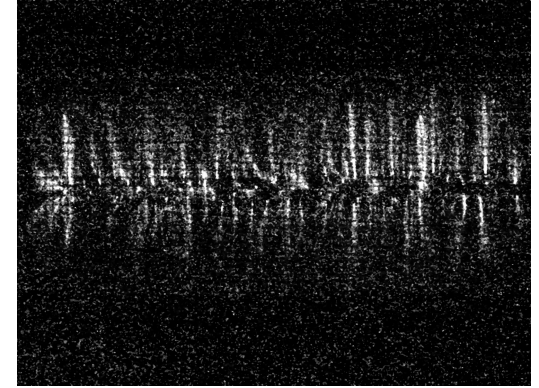
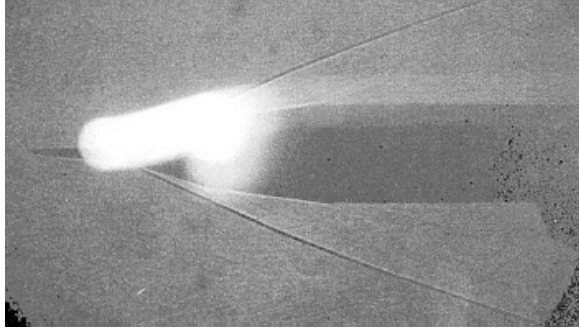
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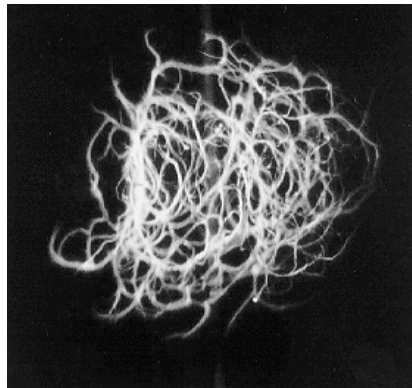
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			19a. NAME OF RESPONSIBLE PERSON



# WEAKLY IONIZED GASDYNAMICS



**RESEARCH OBJECTIVE: Understand, Predict, And Control Weakly Ionized Flows To Revolutionize The Performance Of Aerospace Vehicles**





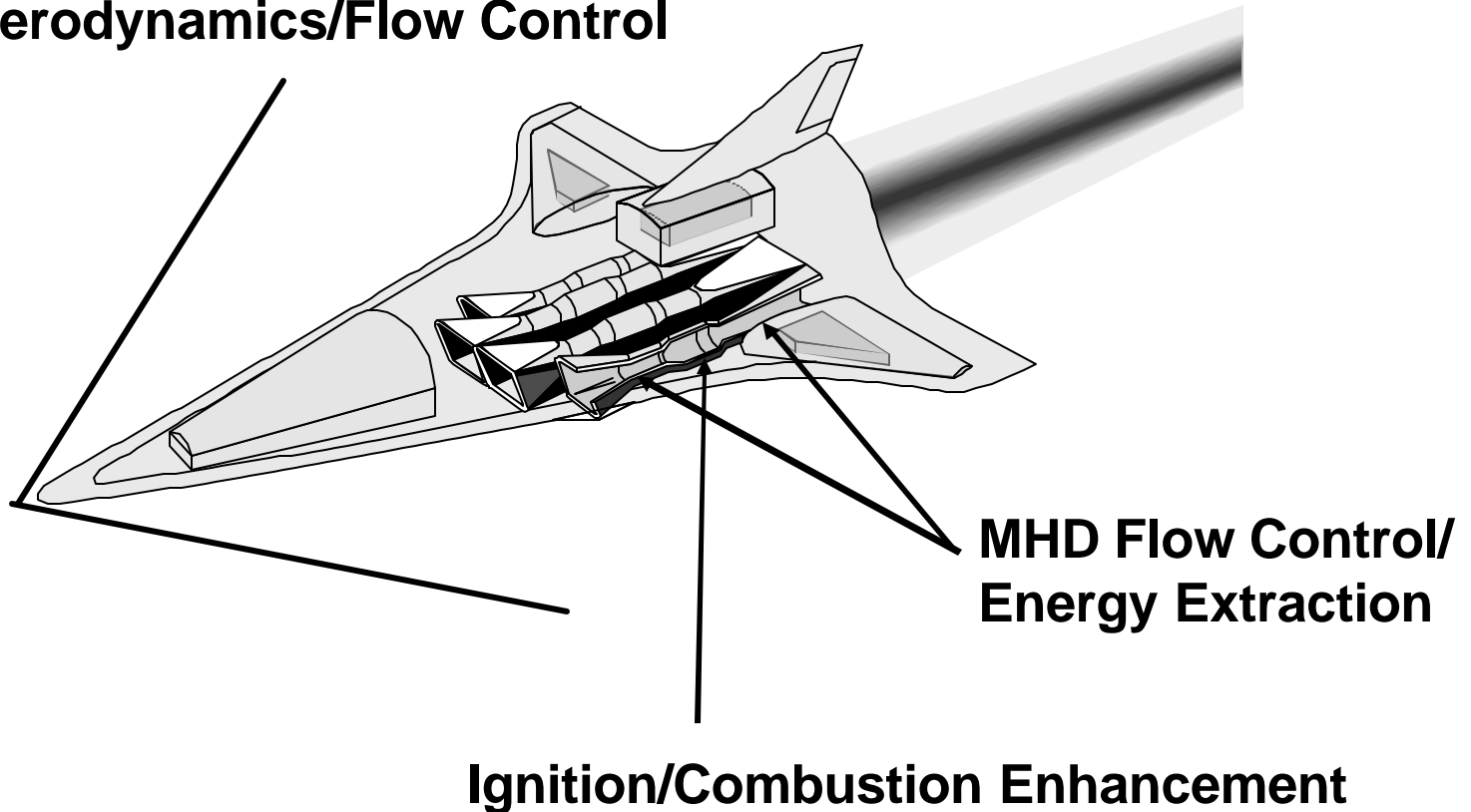
## PRESENTATION OUTLINE

- **Research Focus**
- **Research Coordination And Direction**
- **Selected Research Accomplishments**
- **Summary**



## RESEARCH THRUST AREAS

**Plasma Aerodynamics/Flow Control**





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## RESEARCH MANAGEMENT

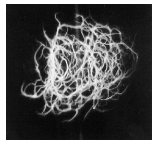
- **Semi Annual Reviews In Russia And The United States**
  - **Weakly Ionized Gas Dynamics Workshops At The American Institute Of Aeronautics And Astronautics Aerospace Sciences Meeting And Exhibit In January**
  - **Summer Workshops In Moscow And Saint Petersburg, Russia**
- **Support For Russian Research Through International Organizations**
  - **International Science And Technology Center (ISTC)**
  - **Civilian Research And Development Foundation (CRDF)**



# WEAKLY IONIZED GASDYNAMICS



## U.S. RESEARCH



Plasma Generation

Robert Vidmar/  
Nevada, Reno

Igor Adamovich/  
Ohio State



MHD

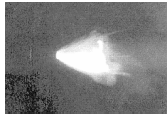
Robert Mac Cormack/  
Stanford

Dennis Jacobs/  
Notre Dame

Datta Gaitonde/  
AFRL/VA

Scott Morris/  
Notre Dame

Doyle Knight/  
Rutgers



Aerodynamics

Norm Malmuth/  
Rockwell

Krishnan Mahesh/  
Minnesota

Bohadan Cybyk/  
JHU/APL

Skip Williams/  
AFRL/VS

Robert Continetti/  
UC San Diego

Bish Ganguly/  
AFRL/PR

Martin Gundersen/  
USC

Yiguang Ju/  
Princeton

Cam Carter/  
AFRL/PR



Ignition/Combustion

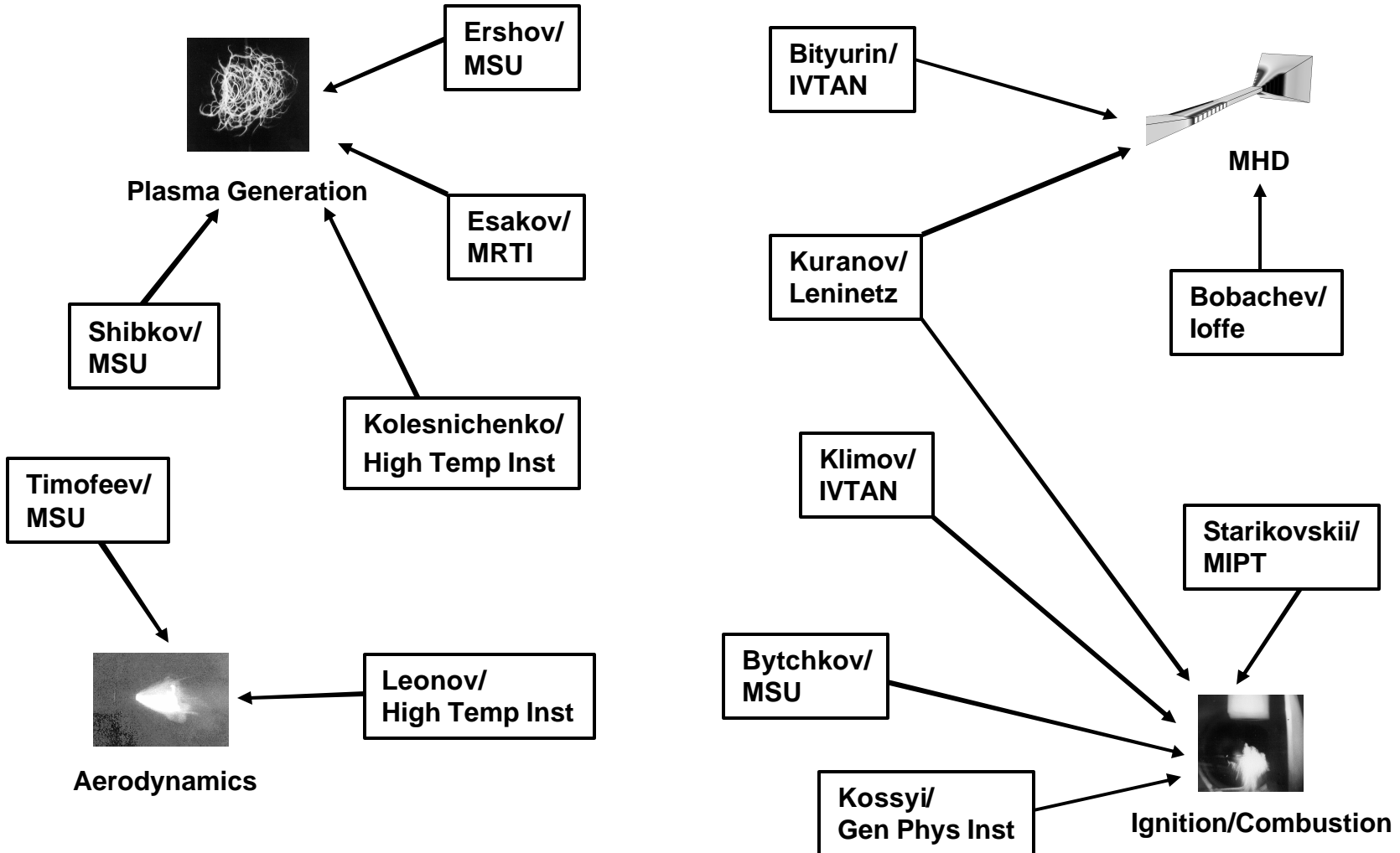




# WEAKLY IONIZED GASDYNAMICS



## RUSSIAN RESEARCH

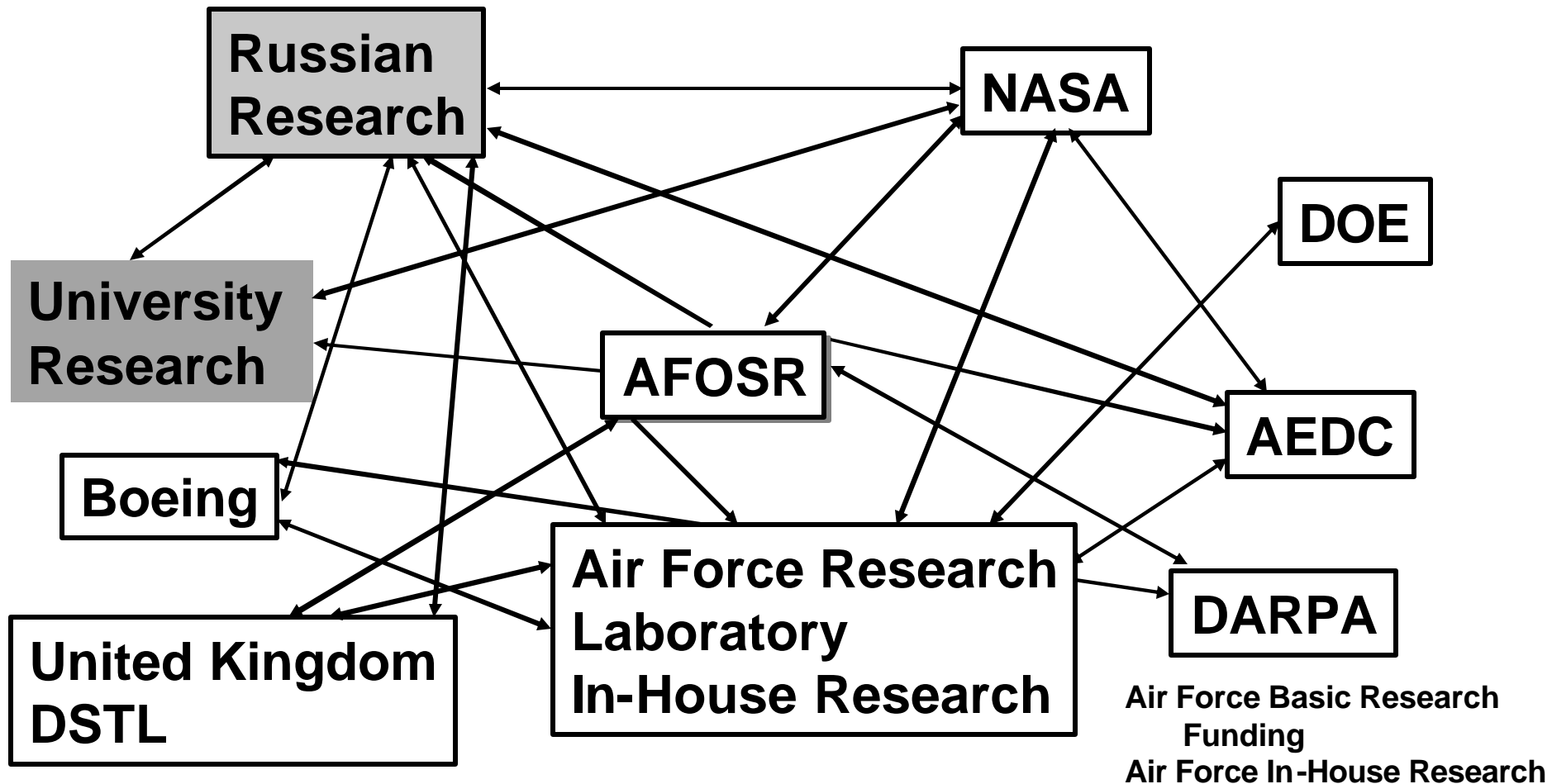




# WEAKLY IONIZED GASDYNAMICS



## RESEARCH COLLABORATION





## PRESENTATION OUTLINE

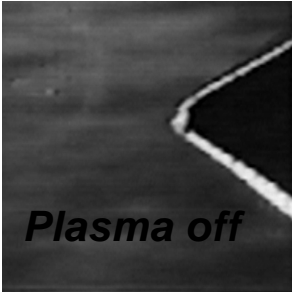
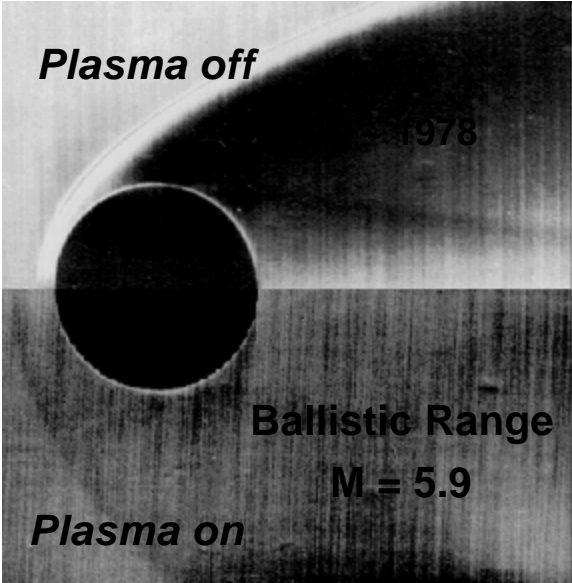
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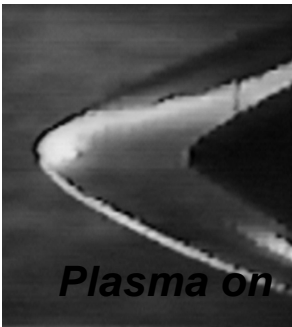
# PLASMA AERODYNAMICS



**RUSSIAN EXPERIMENTS INDICATED SHOCK WAVES WERE WEAKENED IN THE PRESENCE OF WEAKLY IONIZED PLASMAS – POTENTIAL FOR DECREASED VEHICLE DRAG**



**Plasma Torch  
M = 4.0**



**TsNIIMash ~ 1997**

**DRAG  
COEFFICIENT**



**TIME, s**

**Moscow State University ~ 1998**

**SHOCK STAND-OFF  
DISTANCE INCREASED  
(INDICATING WEAKER  
SHOCK WAVES) IN THE  
PRESENCE OF PLASMA**

**QUESTIONS REMAINED  
REGARDING THE PHYSICAL  
MECHANISM FOR THE  
OBSERVED PHENOMENA**

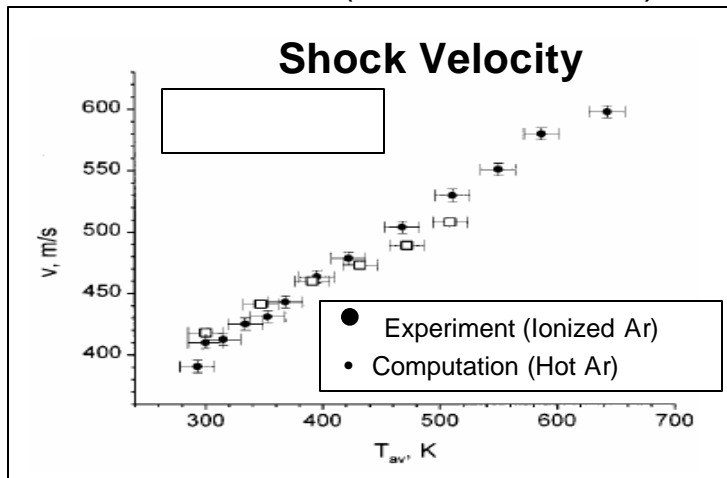


# WEAKLY IONIZED GASDYNAMICS



## U.S. INVESTIGATORS EXPLAIN “ANAMOLOUS” SHOCK BEHAVIOR: THERMAL EFFECT

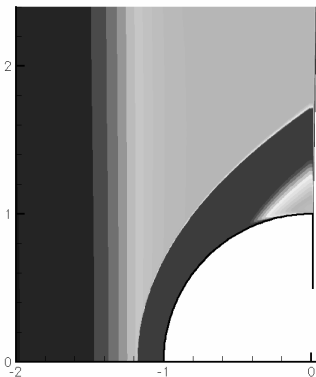
Princeton (Macheret/Miles)



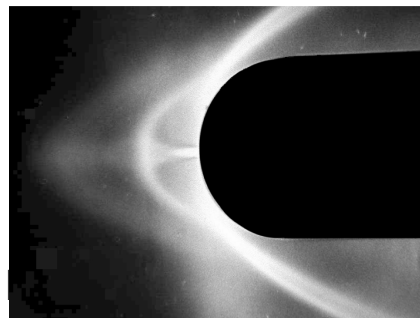
**OBSERVED SHOCK-WEAKENING PHENOMENA RESULTS WHEN TEST MEDIUM IS HEATED DURING PLASMA GENERATION**

- **QUESTIONS REMAIN IF THIS MAY BE EFFICIENTLY UTILIZED**

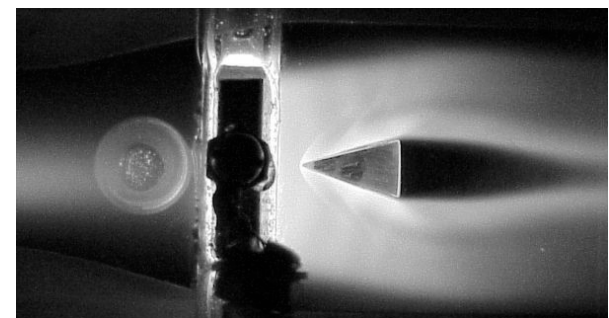
UMinn (Candler)



AFRL/VA (Shang)



OSU (Rich/Adamovich)

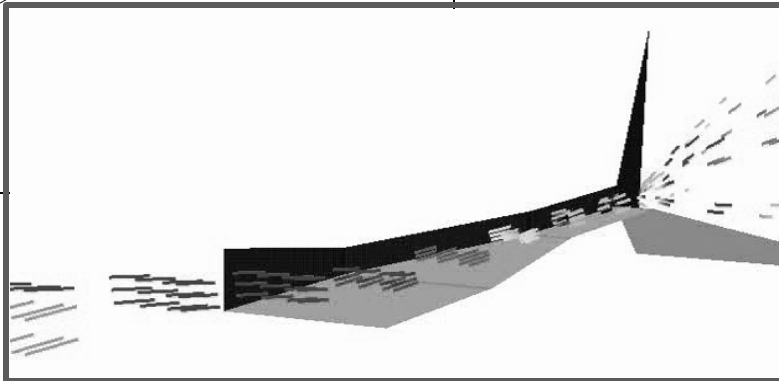
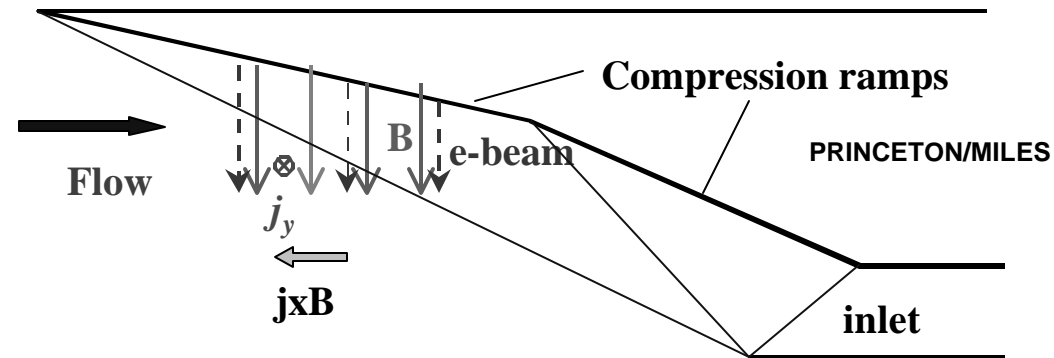
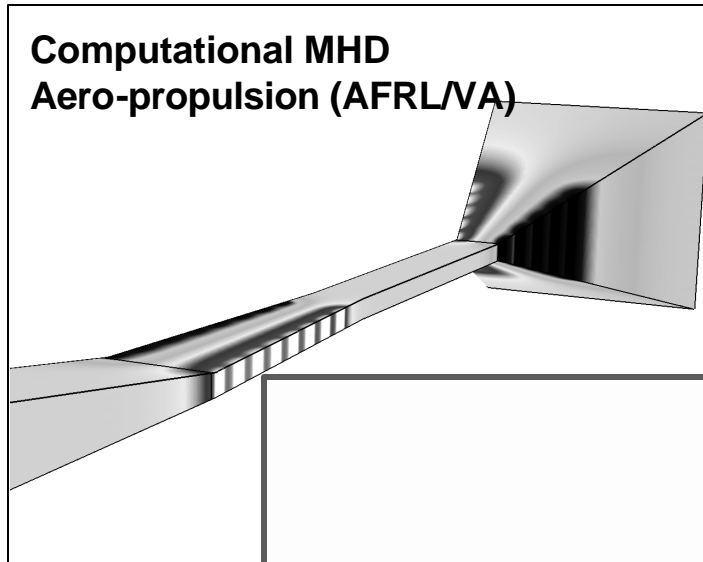




# MAGNETOHYDRODYNAMICS



## MAGNETOHYDRODYNAMIC (MHD) RESEARCH FOCUSES ON SCRAMJET OPTIMIZATION, POWER EXTRACTION/ADDITION

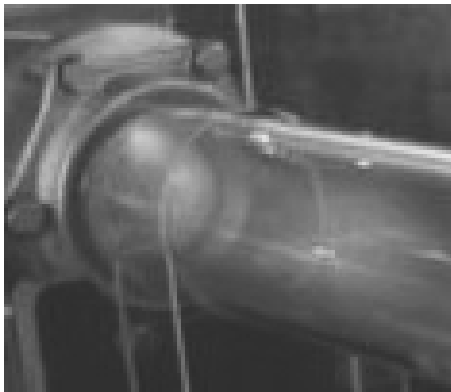


MHD USED TO DECELERATE FLOW  
BEFORE COMBUSTOR, ACCELERATE FLOW  
THROUGH NOZZLE

MODELING SHOWS THAT E-BEAM SUPPORTED EXTERNAL MHD DEVICE CAN BRING SHOCKS BACK TO COWL LIP AT OFF-DESIGN MACH NUMBERS WHILE GENERATING MW-SCALE NET POWER

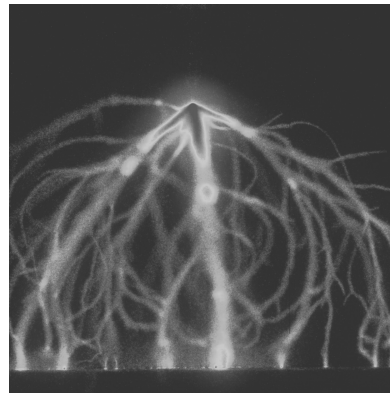


## PLASMA IGNITION ALTERNATIVES



**Glow Discharge**  
(Adamovich/Ohio State)

$$dV/dt = 0$$



**Streamer Discharge**  
(Gundersen/USC)

$$dV/dt > 1 \text{ kV/ms}$$



**Nanosecond Discharge**  
(Starikovskii/MIPT)

$$dV/dt > 1 \text{ kV/ns}$$

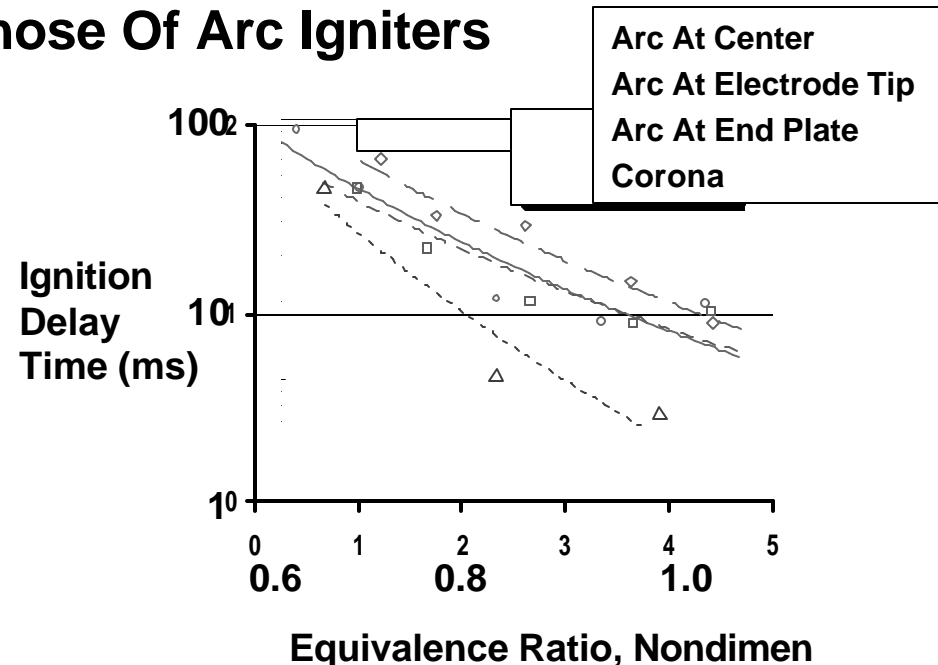
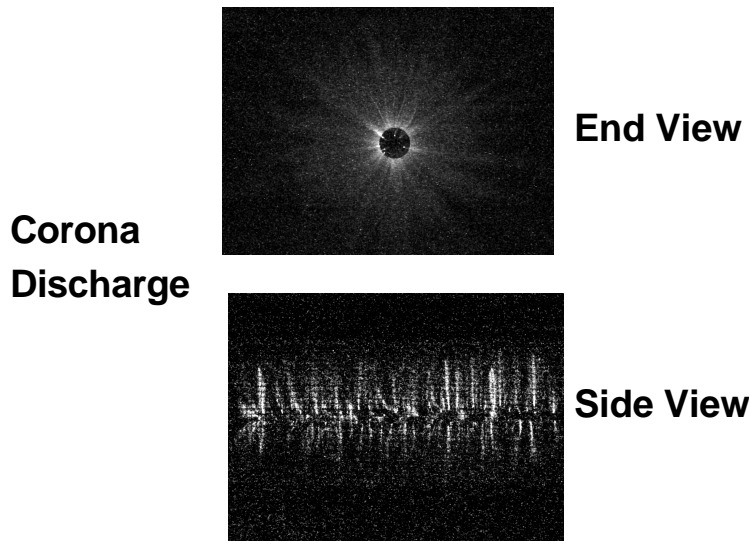


# WEAKLY IONIZED GASDYNAMICS



## SHORT-DURATION (< 100 ns) CORONA DISCHARGE EXHIBITS SUPERIOR IGNITION CHARACTERISTICS FOR HYDROCARBON-AIR MIXTURES

- Ignition Delay Times 1/3 Those Of Arc Igniters



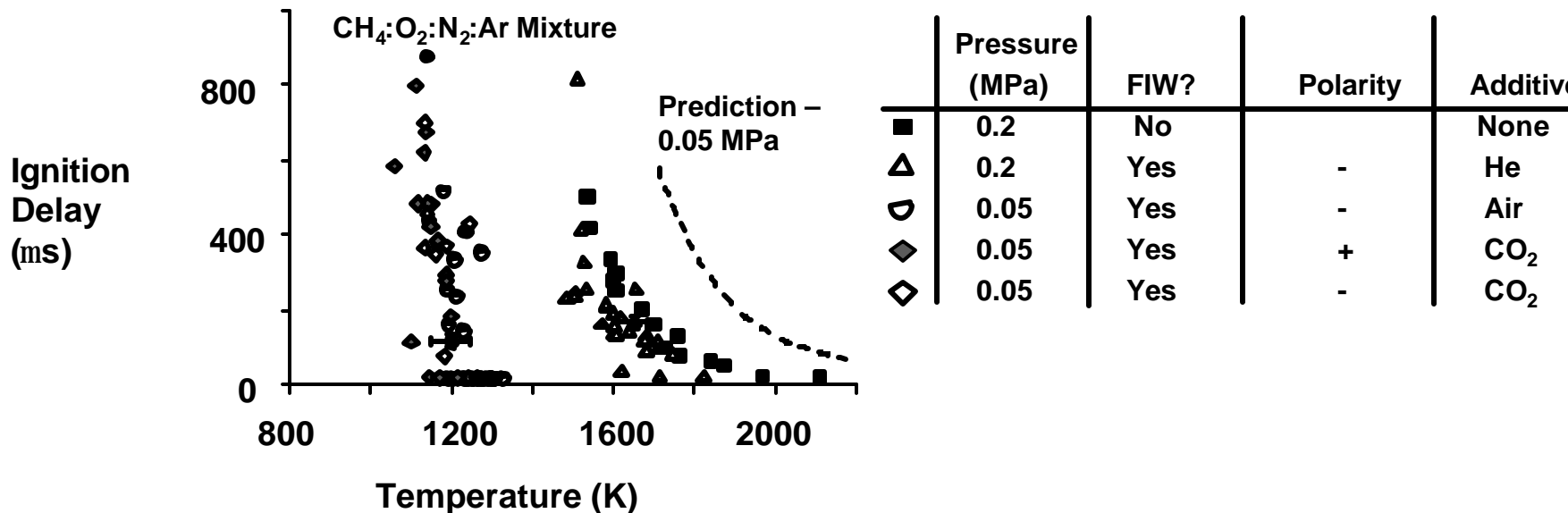
- Corona Contains Multiple Plasma Streamers With  $\approx 10$  eV Energy For Ignition
- Corona Discharge Ignition Based On Activation Of Radical Species Vs. Thermal Ignition For Conventional Arcs





## SHOCK TUBE EXPERIMENTS DEMONSTRATE IGNITION DELAY REDUCTION BY FAST IONIZATION WAVES

- Results Validate Previous Model Predictions

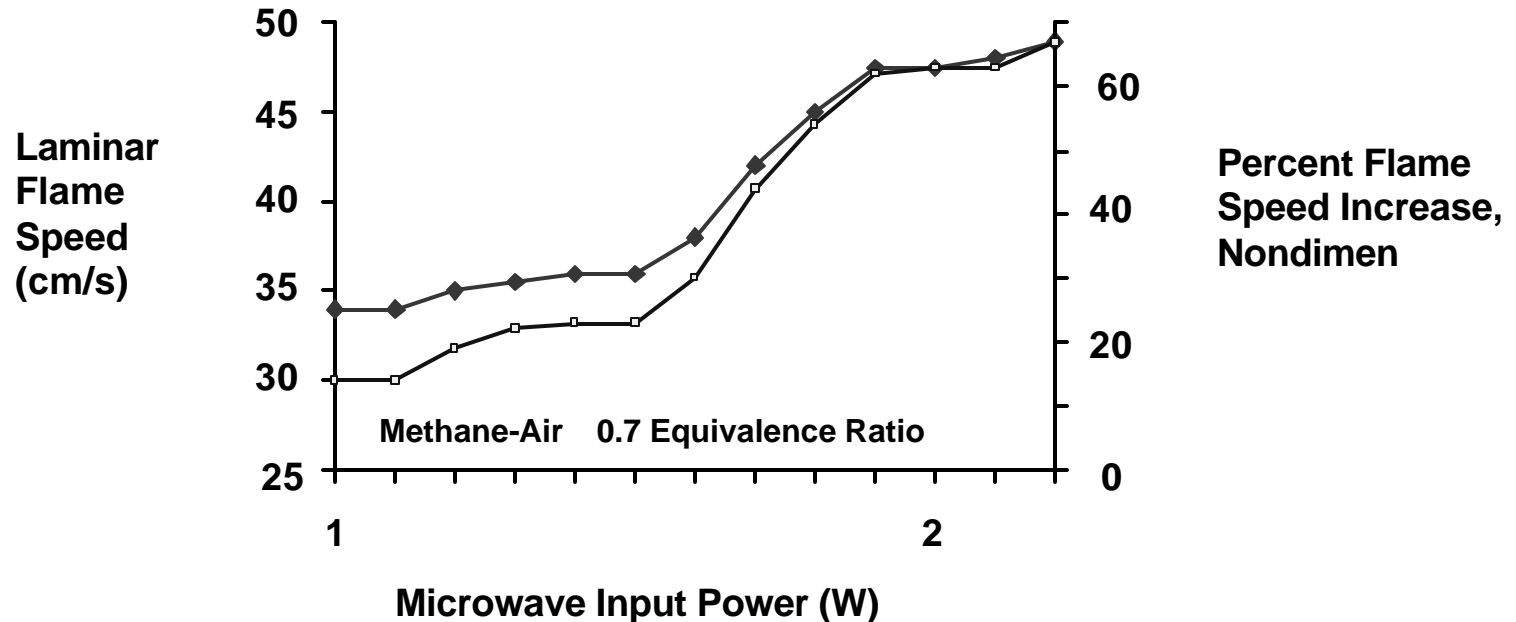


- Nanosecond Corona Discharge at 0.2 MPa Pressure And By Volume Nanosecond Discharge At 0.05 MPa Pressure
- Ignition Not Possible Without Fast Ionization Wave At 0.05 MPa Pressure



## SIGNIFICANT ENHANCEMENT OF LAMINAR FLAME SPEED BY MICROWAVE RADIATION OBSERVED

- Evidence For Combustor Performance Improvements By Microwave Plasmas



- Plasma Strength Was Below Levels Required To Initiate Or Sustain Plasmas, Indicating That Microwaves Were Coupled To Flame-Generated Ions
- Applied DC Voltage Also Found To Increase Flame Speed By Unknown Mechanism

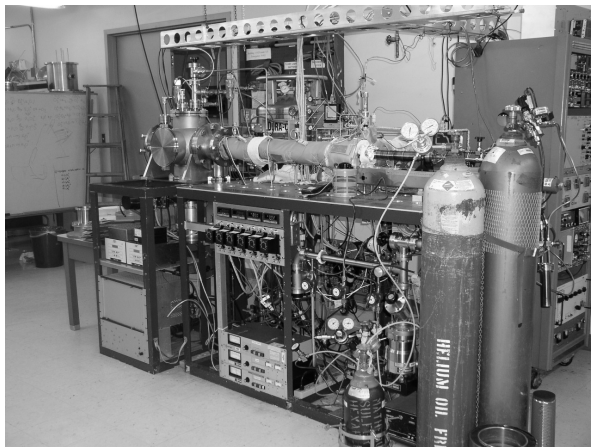
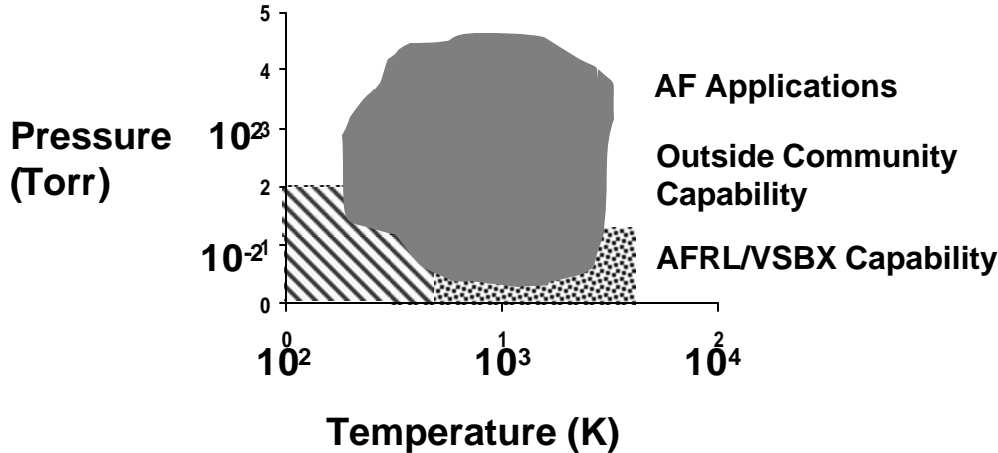


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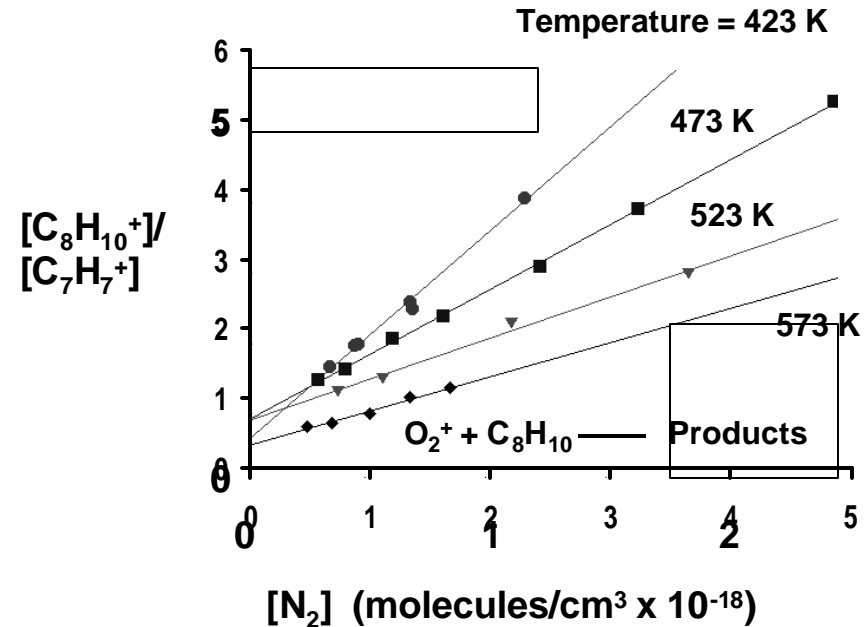


## UNIQUE FACILITIES PROVIDE REACTION RATE DATA FOR ION-MOLECULE REACTIONS

- Critical Information For Air Plasma Chemistry And Plasma-Enhanced Combustion



Turbulent Ion Flow Tube



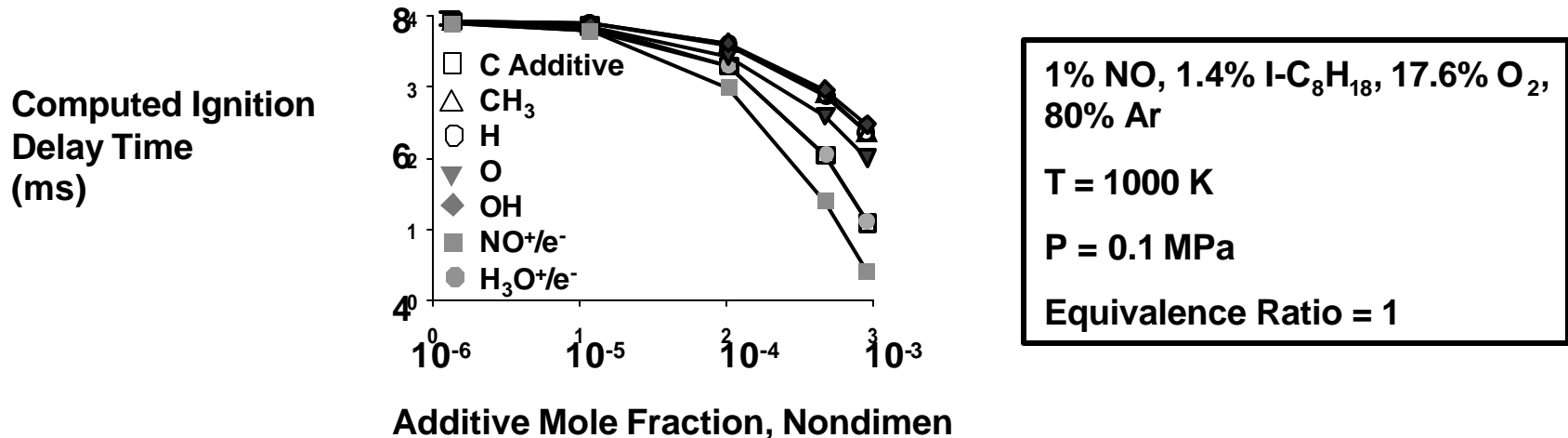


# WEAKLY IONIZED GASDYNAMICS



## EXPERIMENTS PROVIDE REACTION RATE DATA FOR PLASMA-ENHANCED IGNITION MODELS

- Modeling Needed For Plasma Igniter Design



- Supports Development Of The Lindstedt-Maurice-Leung Mechanism (1181 Reactions, 196 Species)
- Aids In The Selection Of JP-8 Surrogate Fuel Composition For Research
- Reveals Important Consequences Of Ionization (Thermal Vs. Chemical Enhancement, Fuel Vs. Air Ionization)

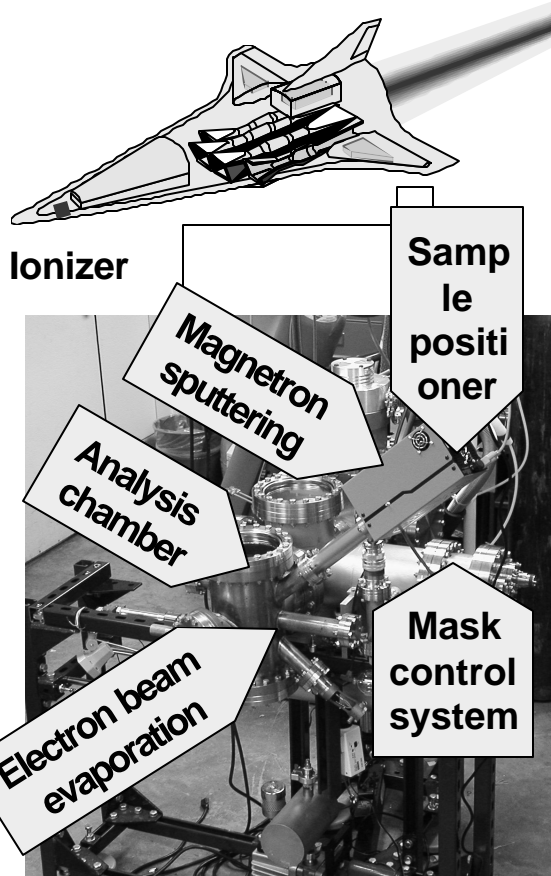


# WEAKLY IONIZED GASDYNAMICS



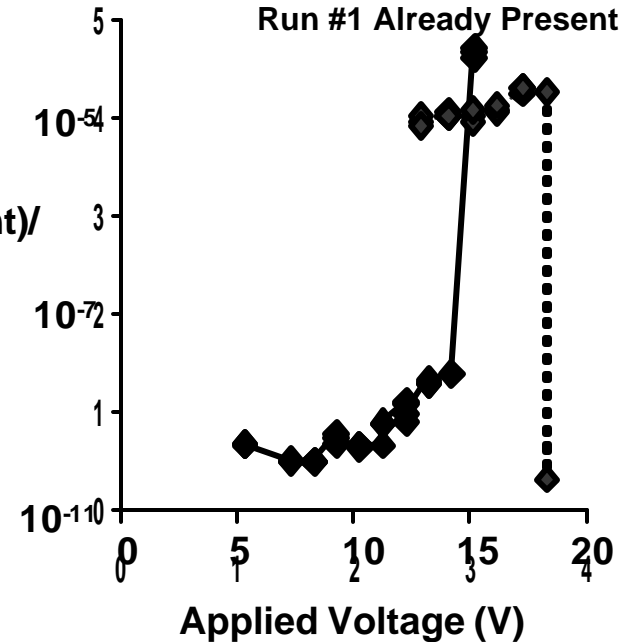
## NOVEL APPARATUS PRODUCES COLD CATHODE ELECTRON EMISSION FROM NANOSTRUCTURED METAL-INSULATOR-METAL (MIM) DEVICES

- Ion Source For Plasma Aerodynamic Enhancement



Run #1 – Initiates Emission Current  
 Run #2 – Emission Current From Run #1 Already Present

(Emission Current)/  
(Device Current)



- MIM Devices Produced By Metal Evaporation And Magnetron Sputter Deposition
- Combinatorial Approach For Rapid Screening To Achieve Optimization Of MIM Structures



## PRESENTATION OUTLINE

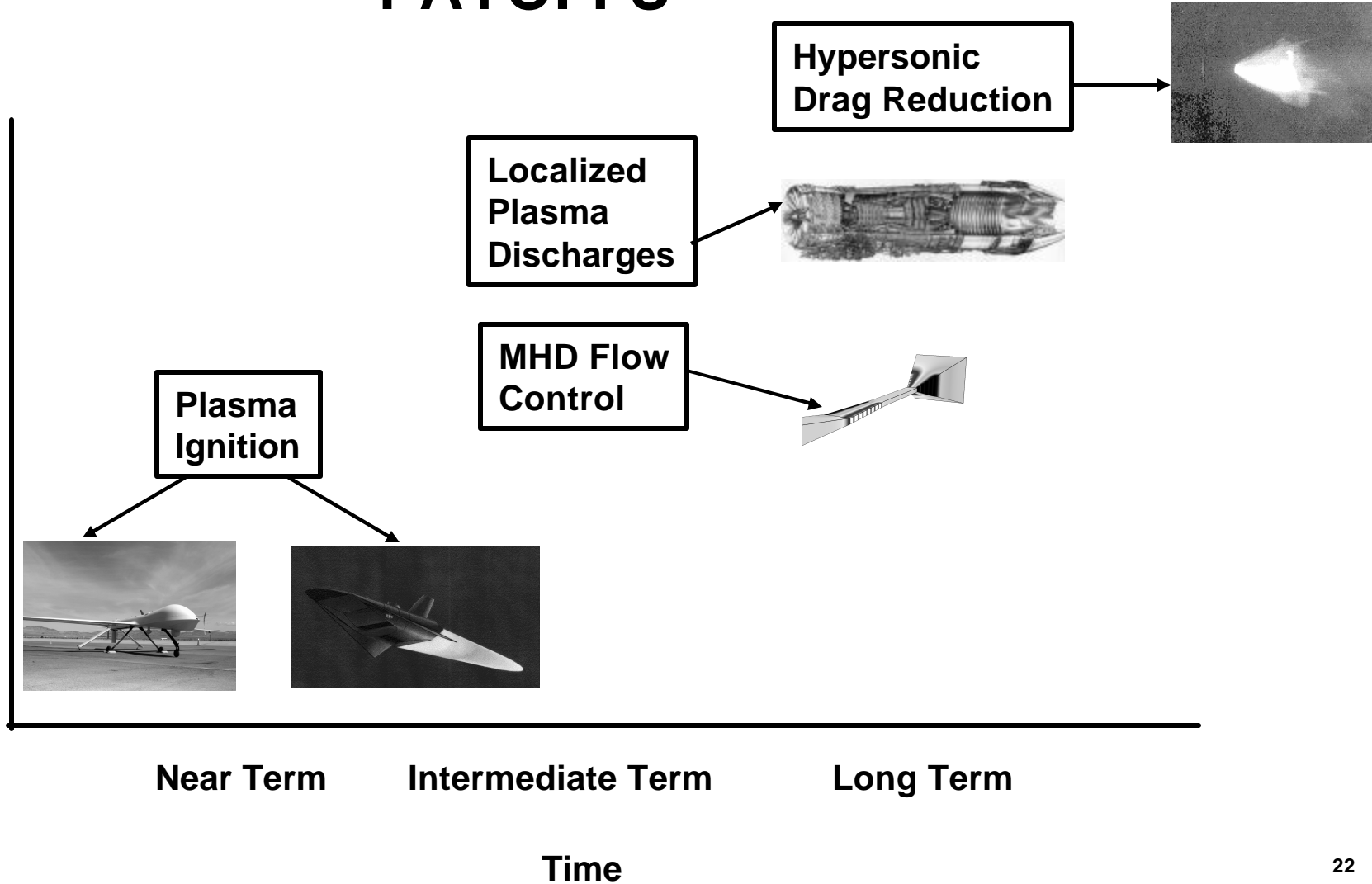
- **Research Focus**
  - **History**
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# WEAKLY IONIZED GASDYNAMICS



## PAYOFFS





# WEAKLY IONIZED GASDYNAMICS



## SUMMARY

- **We Are Conducting And Coordinating International Research On Weakly Ionized Gas Dynamics**
- **Vision Of Future Technology Maturation And Transition**
- **Quality Investigators Performing World-Class Basic Research**