

# Fusion Update from the Advanced Research Projects Agency-Energy (ARPA-E)

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Fusion Power Associates 41<sup>st</sup> Annual Meeting (virtual)  
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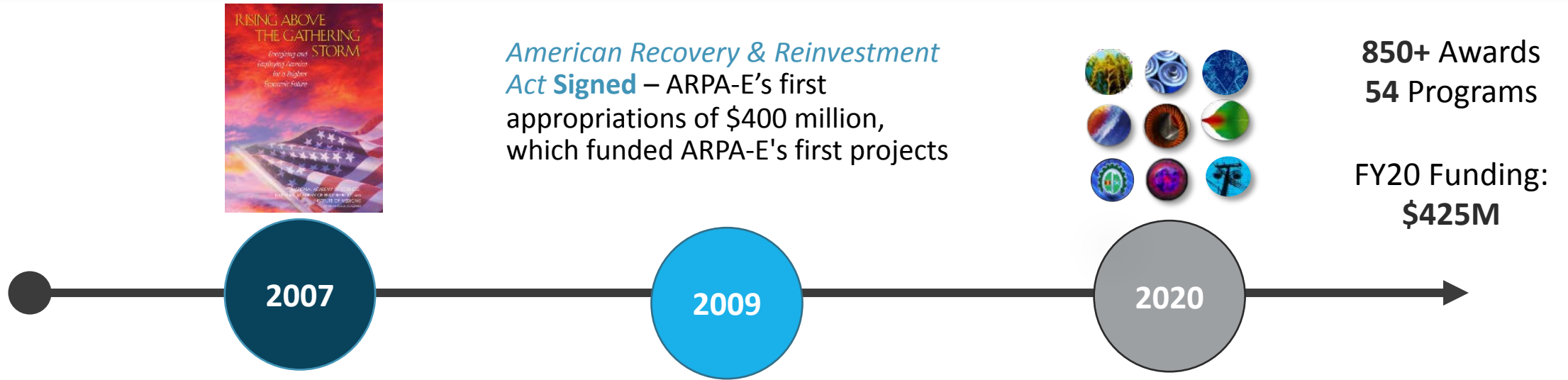
U.S. DEPARTMENT OF  
**ENERGY**

# Outline

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- ▶ Introduction
- ▶ Fusion portfolio and 2020 highlights
- ▶ Plans/opportunities

# ARPA-E's history and mission



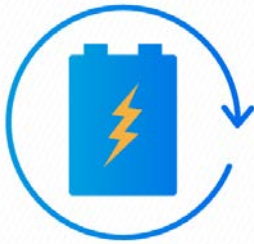
**Goal 1:** Overcome long-term and high-risk technological barriers in the development of energy technologies that...



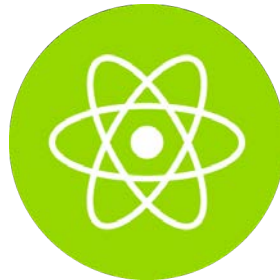
**Goal 2:** Ensure that the U.S. maintains a technological lead in developing and deploying advanced energy technologies.

# Framing of fusion energy within ARPA-E's program portfolio

- ▶ Fusion energy sits at arguably the highest-risk, highest-impact end of ARPA-E's entire energy-technology portfolio
  - Fusion has the potential to be a high-power-density, firm, low-carbon energy source that can possibly be sited near dense population centers
  - Fusion can potentially disrupt the way humans generate and use energy
- ▶ Fusion is valuable risk mitigation for the world to achieve cost-effective “net-zero” GHG emissions while meeting growing energy demand and electrification
  - There are a limited number of low-carbon, primary-energy solutions, all with significant technical and/or socio-economic challenges:



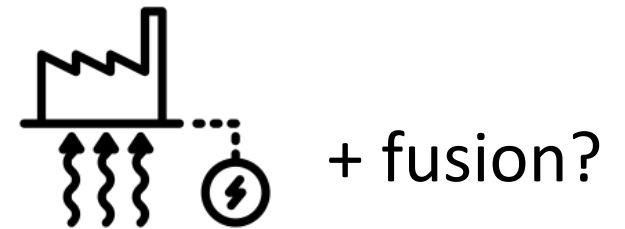
Renewables + long-duration storage



Advanced nuclear fission



Fossil fuels with carbon capture, utilization, sequestration (CCUS)



Enhanced geothermal

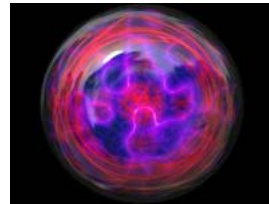
# ARPA-E fusion timeline/programs

Program Director  
Dr. Pat McGrath  
decides to develop  
a fusion program



C. Nehl et al., "Retrospective of the ARPA-E ALPHA Fusion Program," [\*J. Fusion Energy\* 38, 506 \(2019\)](#).

ALPHA



Included three  
fusion projects

Diagnostic  
"capability  
teams"



joint with DOE  
Fusion Energy  
Sciences

# Thought process behind new ARPA-E fusion programs

Aspiration: catalyze a new trajectory toward commercially viable DEMO on a two-decade time scale.

## Technical drivers

## Programmatic drivers

More low-cost approaches at higher levels of fusion performance



+ diagnostic teams

Innovative solutions from the first wall to the heat exchanger



joint with FES

Engage larger portion of the fusion R&D community

Leverage SotA expertise/capabilities

Incentivize publicly and privately funded teams to work together

# BETHE\* program: Catalyze R&D to deliver a larger number of lower-cost fusion concepts at higher performance levels



Advance the performance of lower-cost concepts

Concept development

Capability teams

Lower the cost of more-mature concepts

Component technology development

- Projected net-gain experiment for  $\lesssim$  \$100M
- Specify entry/exit milestones
- Funding ceiling commensurate w/ achieved performance
- Leverage capability teams
- Selected projects include mirrors, spheromak, MIF, Z pinch,  $\mu$ -catalyzed fusion

- Potentially enable overnight capital cost <\$2B, <\$5/W
- Selected projects include fast-ramping tokamak HTS central solenoid, new approaches to stellarator magnets, next-gen high-bandwidth lasers

# BETHE portfolio (\$35M + \$5M FES): 17 projects across 3 technical categories



Category A:  
Concept development



Category B: Component  
technology development



Category C:  
Capability teams



Prime recipients: 7 universities, 5 private companies, 5 national labs; click [here](#) for full list of project teams.



# GAMOW\* program: Accelerate R&D in fusion enabling technologies to support commercially viable fusion concepts



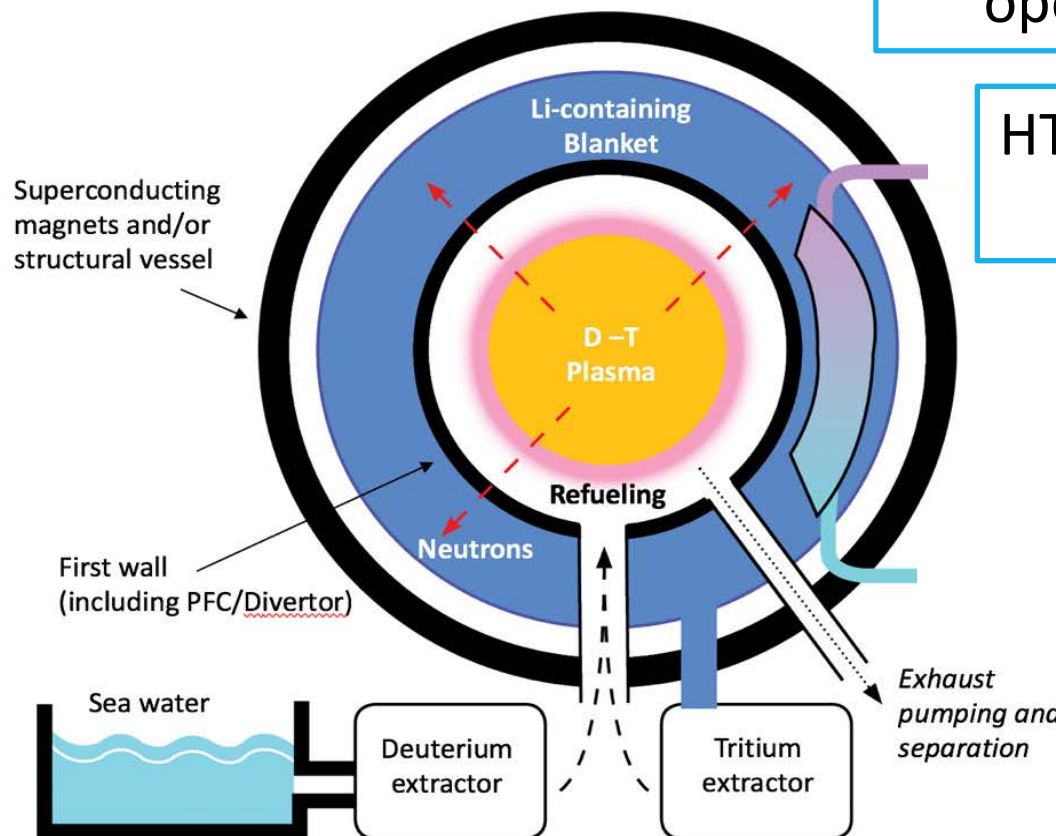
Deployable in experiments well within a decade

Device simplification or elimination of entire subsystems

Significant cost reduction

Improvements in RAMI, safety, sustainability

Joint program with FES



>900-K blanket operation

HTS tape <\$10/kA-m, substrate >3 GPa

<1000-Ci (100-mg) T annual release

>10-MW/m<sup>2</sup> continuous power handling at 1st wall

<0.75-kG T inventory for 500-MW<sub>th</sub> system

\*Galvanizing Advances in Market-aligned fusion for an Overabundance of Watts; click [here](#) for program overview.

# GAMOW portfolio (\$29M): 14 projects across 7 technical categories



## Integrated First-Wall and Blanket Technology

- Fusion Energy Reactor Models Integrator (FERMI), *Oak Ridge National Laboratory*

## Plasma-Facing Components (PFC) and Divertor

- Renewable low-Z wall for fusion reactors with built-in tritium recovery, *University of California: San Diego*

## Tritium Fuel Cycle

- Interfacial-Engineered Membranes for Efficient Tritium Extraction, *Colorado School of Mines*
- Direct LiT Electrolysis Process Modeling & Scale up, *Savannah River National Laboratory*
- EM-Enhanced HyPOR Loop for Fast Fusion Fuel Cycles, *Savannah River National Laboratory*

## Joint program with FES

### Superconducting Magnets

- Advanced HTS Conductors Customized for Fusion, *University of Houston*

### High-efficiency electrical-driver systems

- Wide Band Gap Semiconductor Amplifiers for Plasma Heating and Control, *Princeton Fusion Systems*
- AMPERE - Advanced Materials for Plasma-Exposed Robust Electrodes, *University of California: Los Angeles*
- High Efficiency, Megawatt Class Gyrotrons for Instability Control of Burning Plasma Machines, *Bridge 12 Technologies*

## Novel Fusion Materials

- Advance Castable Nanostructured Alloys for First-Wall/Blanket Applications, *Oak Ridge National Laboratory*
- Ultra High Flux DT Neutron Source for Accelerated Testing of Fusion Materials and Subsystems to Reactor-relevant DPA Levels, *Phoenix LLC*
- ENHANCED Shield: A Critical Materials Technology Enabling Compact Superconducting Tokamaks, *Stony Brook University*

## Advanced and Additive Manufacturing

- Plasma Facing Component Innovations by Advanced Manufacturing and Design, *Oak Ridge National Laboratory*
- Microstructure Optimization and Novel Processing Development of ODS Steels for Fusion Environments (MONDO-FE), *Pacific Northwest National Laboratory*

# Tech-to-Market (T2M) priorities for the ARPA-E fusion portfolio

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▶ Investor engagement

▶ Market studies



▶ Updated reactor-costing tool, studies, and support of concept teams



▶ Engaging NGOs (who will be the advocates for the ultimate commercial adoption of fusion)

▶ Supporting/coaching our project teams (on development plan, team building, securing follow-on funding, etc.)

# Summary of findings from ARPA-E report *Early Markets for Fusion Energy*

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- ▶ Most-promising early markets are high-priced electricity markets around the world (up to \$110/MWh, e.g., Singapore, Japan, California)
  - Eventually, fusion may need to cost <\$50/MWh to access very large markets (to compete with natural gas w/CCS and \$50/ton carbon tax)
- ▶ Load-following may not be economically feasible for fusion (it cannot afford to sit idle half the time due to large capital cost)
  - Integrated thermal storage may be needed so plant can run at high capacity factor
- ▶ Process-heat and hydrogen-production markets will be tough early markets (also, fusion may not be able to achieve the needed high temperatures)
- ▶ Desalination & direct air capture alongside power generation or retrofitting coal power plants may help make fusion more economically competitive

See Malcolm Handley's [talk](#) from BETHE [kickoff](#), and read the report when it is released in the near future.

# Upcoming opportunities

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- ▶ [Teaming partner announcement](#) posted for potential [OPEN 2021](#) FOA (agency-wide)
  - Fusion energy
  - Energy/electrification applications of low-temperature plasmas (LTP)
  - Nuclear waste disposition
  
- ▶ Recruit my “successor” to start hopefully no later than mid-2022

Please contact me to discuss any of the above: [scott.hsu at hq.doe.gov](mailto:scott.hsu@hq.doe.gov).

Check <https://arpa-e-foa.energy.gov> regularly for new FOAs.

Sign up for ARPA-E [newsletter](#) to receive updates.

# Join the Team that is Transforming the Energy of Tomorrow

## PROGRAM DIRECTOR



- Program development
- Active project management
- Thought leadership
- Explore new technical areas

## TECHNOLOGY-TO-MARKET ADVISOR



- Business development
- Technical marketing
- Techno-economic analyses
- Stakeholder outreach

## FELLOW



- Independent energy technology development
- Program Director support
- Organizational support

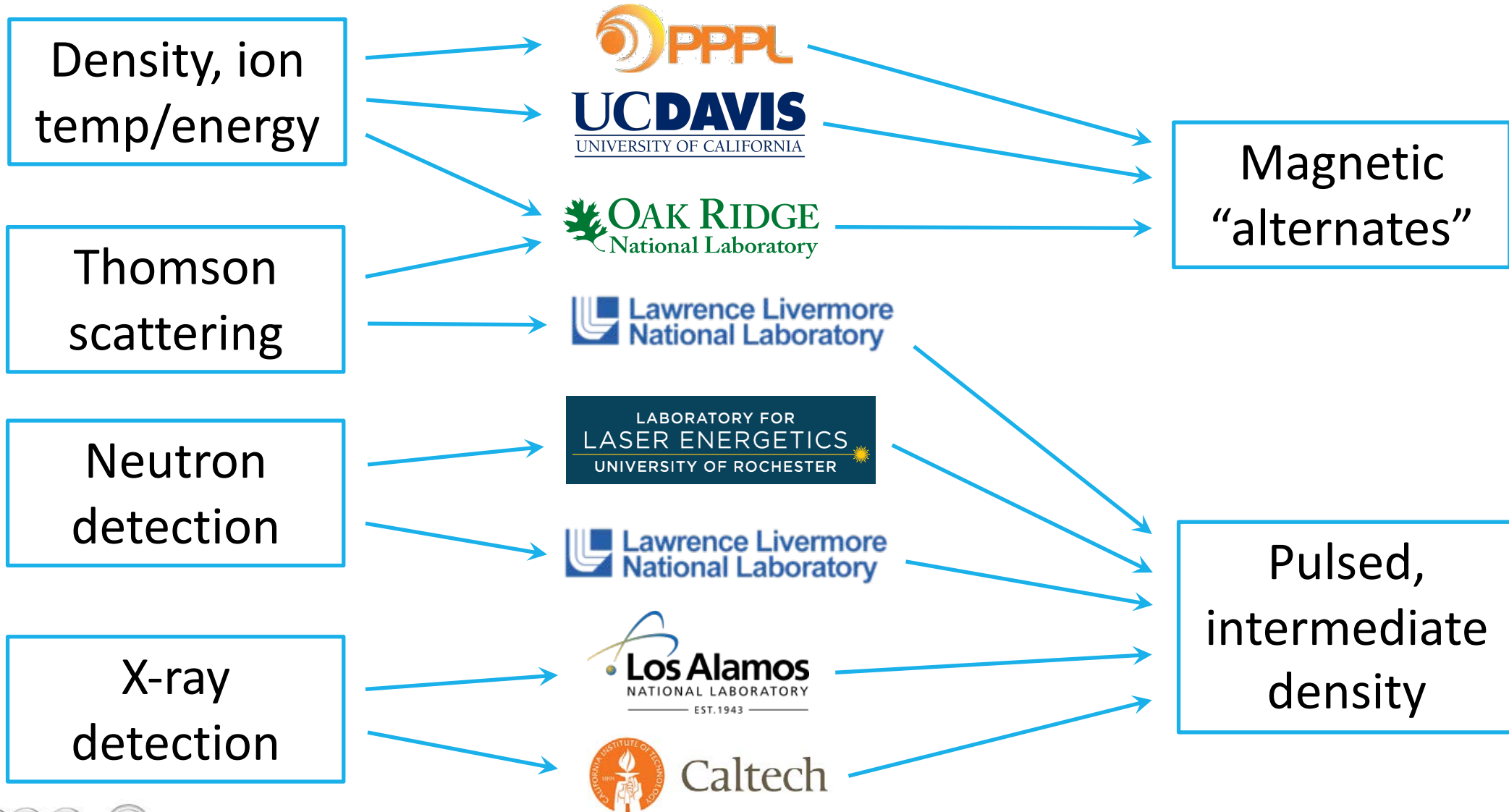
Learn more and apply: [www.arpa-e.energy.gov/jobs](http://www.arpa-e.energy.gov/jobs) or [arpa-e-jobs@hq.doe.gov](mailto:arpa-e-jobs@hq.doe.gov).



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<https://arpa-e.energy.gov>

# Diagnostic capability teams: “Transportable” diagnostics & expert diagnosticians to support ARPA-E fusion concept teams (\$7.4M)





# BETHE capability teams

Lead Institution	Primary Model/Codes or Diagnostic	Teams supported
	High-fidelity moment-kinetic models, Gkeyll	Wisconsin, LANL, UMBC, General Fusion
<b>SapientAI, LLC</b>	Data analytics, machine learning, AI	CTFusion, LANL, General Fusion
	Rad-MHD (FLASH), hybrid/kinetic (TriForce), kinetic PIC (OSIRIS)	MIFTI, PFS/PPPL, LANL, Compact Fusion Systems
	RF modeling	Wisconsin, PFS/PPPL, UMBC
	Solid-state X-ray imager; multi-chord spectroscopy	tbd
	Doppler-free saturation spectroscopy ( $B$ and $E$ )	PFS, TAE (via INFUSE)