National Aeronautics and Space Administration

NASA EXPLORES

Heavy Ion Single-Event Effects (SEE) Test Facility Status and General Implications for Space System Evolution

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Outline

Origins – why do we need SEE testing?

Evolutions – how are SEE test needs changing?

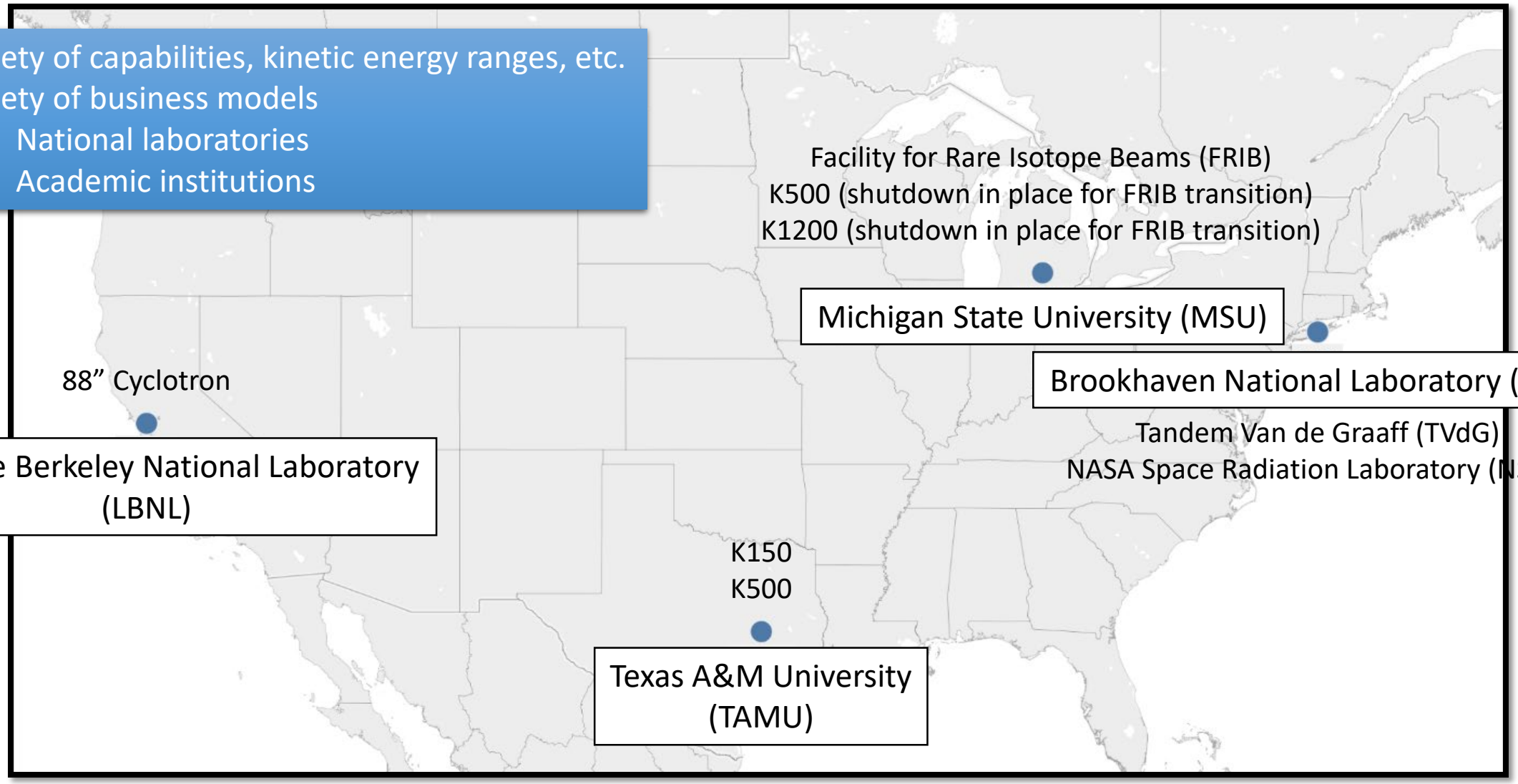
Gaps – do we have access to sufficient capacity and necessary capabilities? (requires us to project ahead many years…easier said than done)

Mitigations – what can we do to overcome challenges?

Talk will focus on heavy ion SEE testing in the United States (may generalize)
Large and diverse trade space – just one perspective
SEE test facilities are increasingly critical infrastructure for many economic sectors
…related topics could extend to proton and neutron test facilities too…

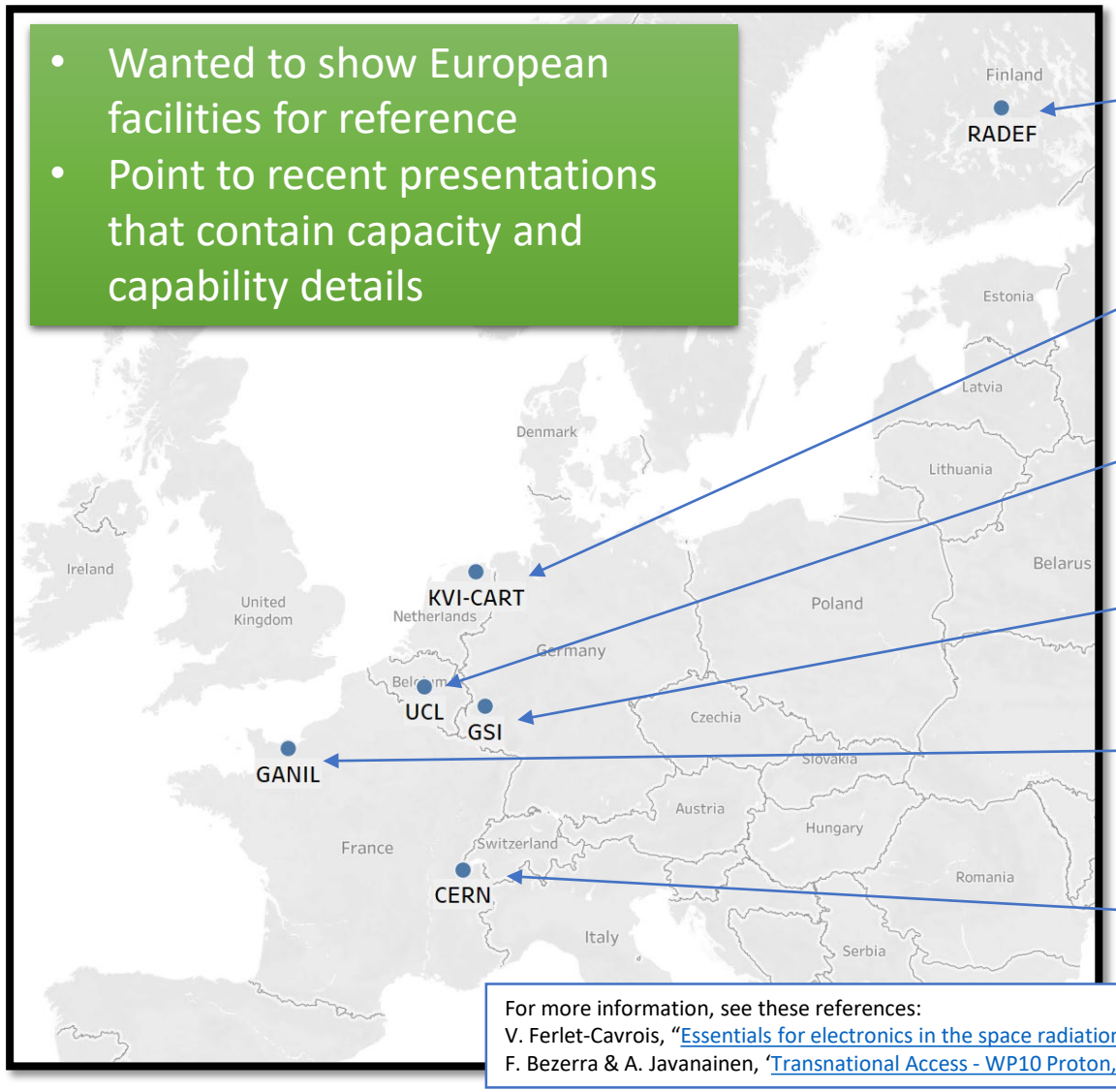
U.S. Heavy Ion Test Facilities (*currently*)

- Variety of capabilities, kinetic energy ranges, etc.
- Variety of business models
  - National laboratories
  - Academic institutions



European Heavy Ion Test Facilities (*currently*)

- Wanted to show European facilities for reference
- Point to recent presentations that contain capacity and capability details



RADiation Effects Facility (RADEF), University of Jyväskylä, Finland.

Kernfysisch Versneller Instituut (KVI) - Center for Advanced Radiation Technology (CART), University of Groningen, The Netherlands

Université Catholique de Louvain (UCL), Louvain-la-Neuve, Belgium

Gesellschaft für Schwerionenforschung (GSI), Darmstadt, Germany

Grand Accélérateur National d'Ions Lourds (GANIL), Caen, France

European Organization for Nuclear Research (CERN), Meyrin, Switzerland; Prévessin-Moëns, France

For more information, see these references:
V. Ferlet-Cavrois, "Essentials for electronics in the space radiation environment - Test methods and facilities", RADSAGA/RADNEXT, May 2021.
F. Bezerra & A. Javanainen, 'Transnational Access - WP10 Proton, heavy ion and alternative beams and irradiation', RADSAGA/RADNEXT, May 2021.

ORIGINS

Why do we need SEE testing?

Breaking Down Radiation Effects

Ionizing Radiation Effects

Total Ionizing Dose (TID)

Total Non-Ionizing Dose (TNID)

Single-Event Effects (SEE)

Primarily high-energy protons and **heavy ions**

Not including charging

Non-Destructive

Destructive

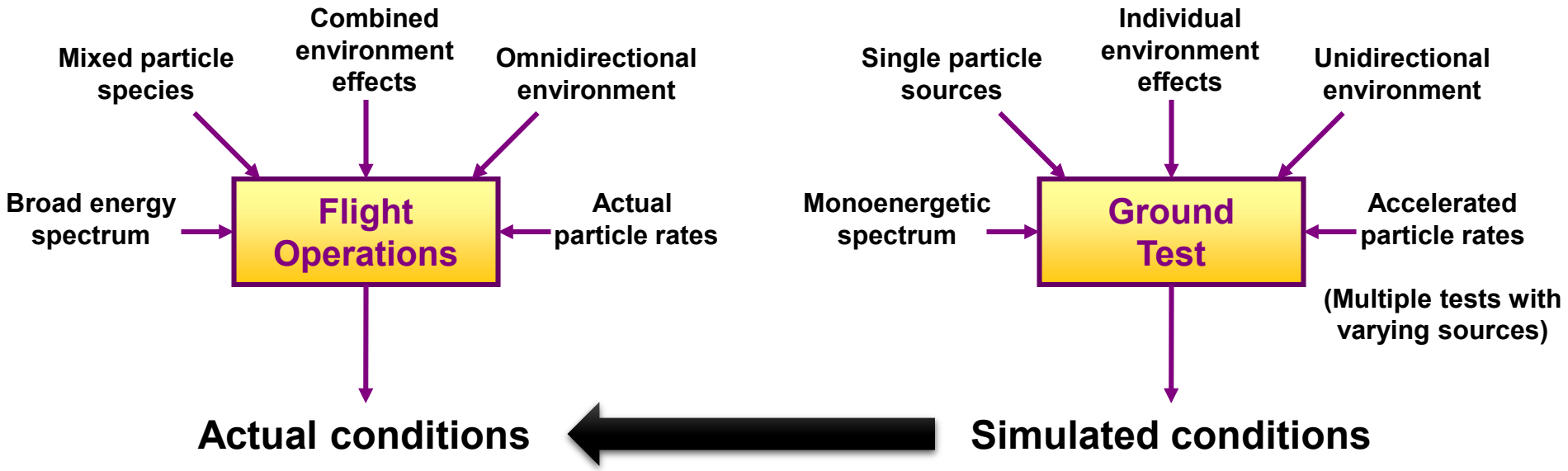
SEE Testing

- Why do testing? (two primary goals)
  1. To determine the presence and characteristics of single events
     - Destructive or non-destructive?
     - Voltage- and/or temperature-dependent?
     - *List goes on for a quite a while…*
  2. To calculate bounding SEE rates as part of availability and/or reliability assessments for a given mission, environment, application, and lifetime (MEAL) – this is what matters to designers, system engineers, etc.
- SEE testing is usually performed at particle accelerator facilities, which irradiate an electronic device target (or board or box) with ions

Adapted from S. Buchner, *SERESSA 2011*, Toulouse, France.

SEE Testing Fidelity

Ground ≠ space – radiation effects practitioners need to understand and account for the differences



Graphic prepared by K. A. LaBel, NASA GSFC, 2008.

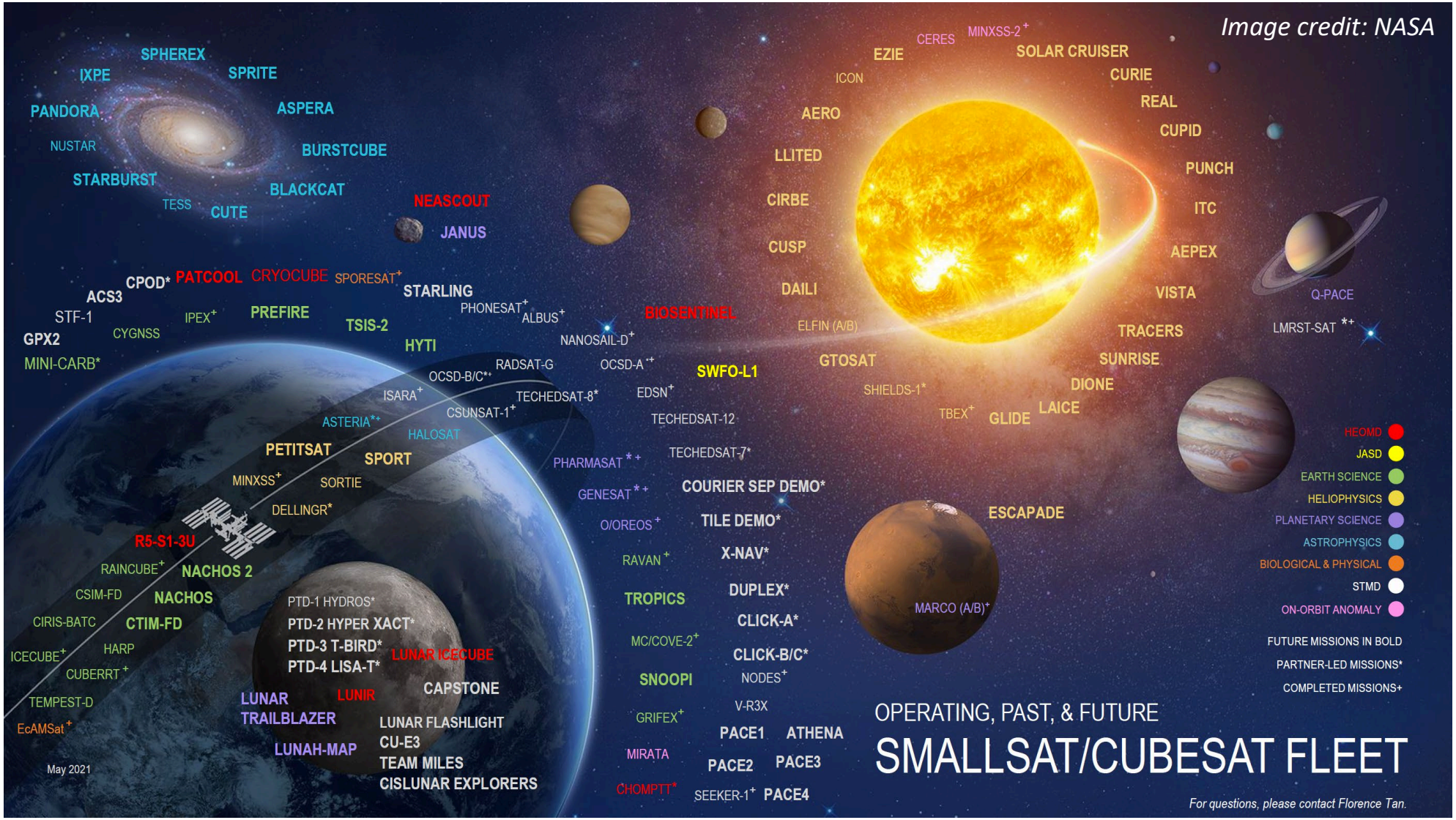
How accurate is ground-based SEE testing in predicting space-based performance? Increasingly important considerations for new technologies

EVOLUTIONS

How are SEE test needs changing?

Program needs are growing and driving technology requirements

Space Community Growth and Diversification



NASA SmallSat/CubeSat Fleet – access link (<--) for more information on individual missions

Space Community Growth and Diversification

Image credit: NASA

Image credit: NASA

Launched: 23-April-2021


Image credit: NASA

Human Landing System

Commercial Crew Program

Space Community Growth and Diversification

https://www.defense.gov/

https://www.defense.gov/

Defense Applications

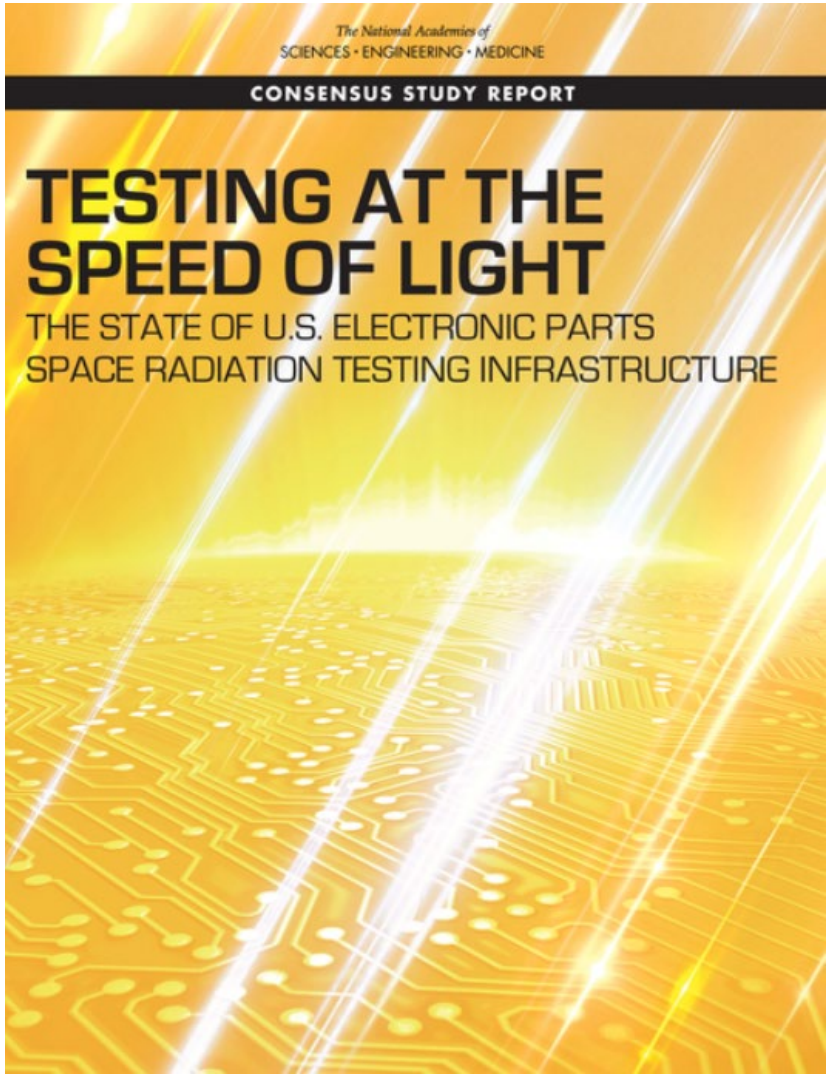
GAPS

Do we have access to sufficient capacity and necessary capabilities?

Recent Assessments (NASEM 2017-2018)

- Key findings
  - Growing use and tightening supply
  - Infrastructure showing signs of strain
  - Aging workforce in a domain that requires specialized training and skills
  - Fast-moving technology
- Points to / needs
  - More organizational coordination
  - Test facility sustainment & new investments
    - Coupled with appropriate research & development
  - Workforce development

At least one detailed assessment pre-dated this work, Aerospace Corp. TOR-2015-00473.



https://doi.org/10.17226/24993

Recent Assessments (AoA 2019)

- Key findings
  - Existing heavy ion SEE test facilities cannot meet current or future SEE test demand (~5000 hour/year gap)
  - Department of Defense efforts as well as U.S. Government and commercial space are driving significant increases in SEE testing demand
  - Current heavy ion accelerators for SEE testing at U.S. universities and Department of Energy labs have limited capacity and capability
  - More complex electronics (e.g., processors, ASICs, FPGAs) require more test hours
  - More advanced electronics and packaging (e.g., 3D ICs, flip-chip packages, system-on-a-chip, or system-in-a-package) require higher ion energies >100 MeV/amu

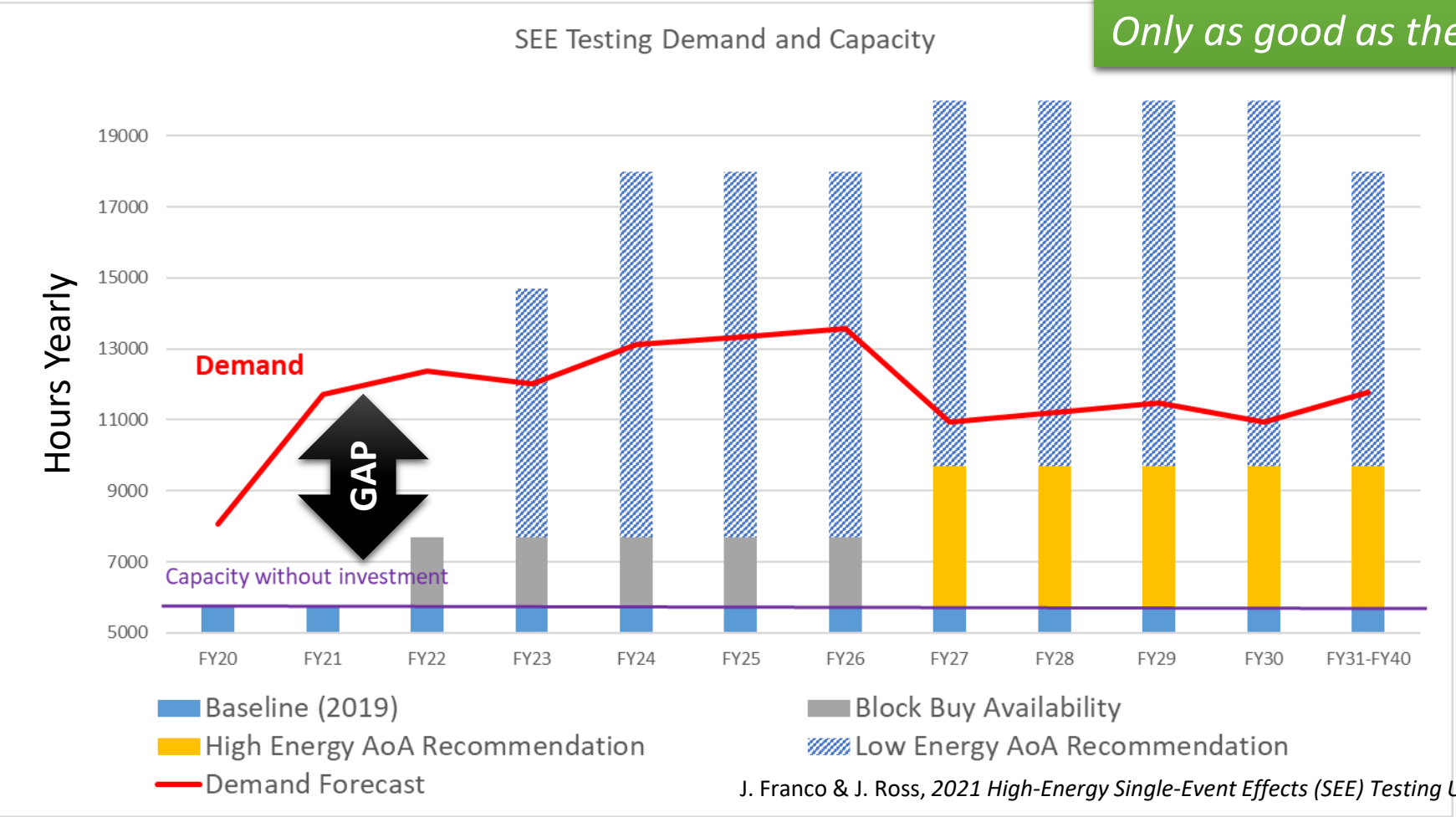
AoA Findings and Recommendations are Independent and Non-Binding

J. Franco & J. Ross, *2021 High-Energy Single-Event Effects (SEE) Testing Users Meeting* (slides)

Recent Assessments (AoA 2019)

Only a snapshot in time

Only as good as the data collected

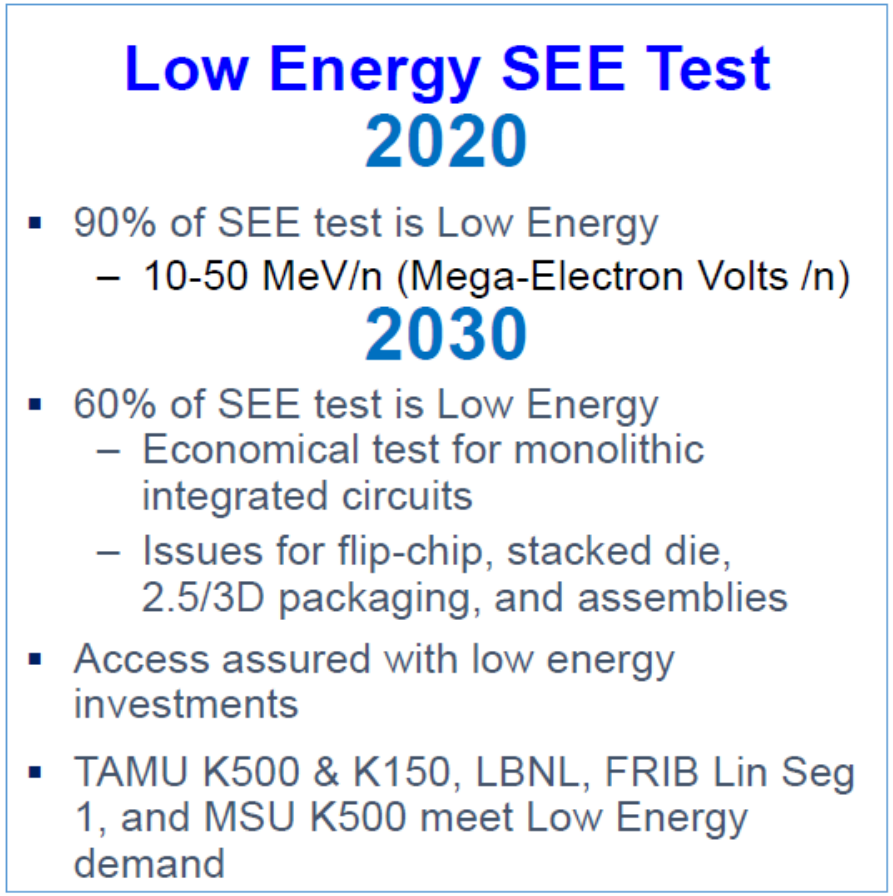


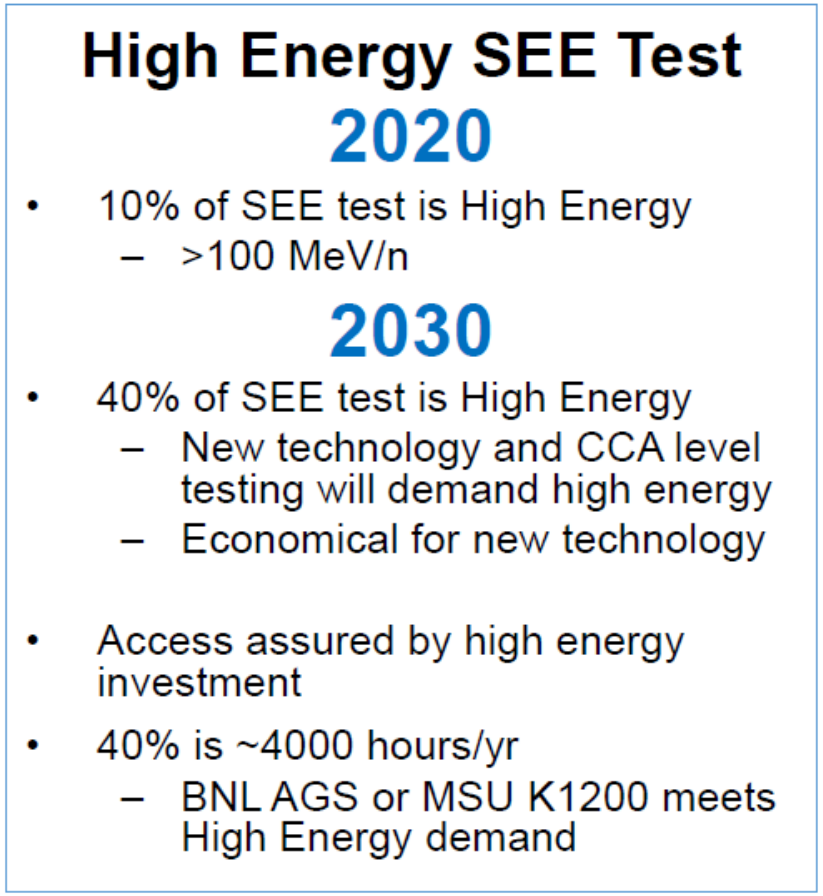
J. Franco & J. Ross, *2021 High-Energy Single-Event Effects (SEE) Testing Users Meeting* (slides)

Demand forecast is based on Fiscal Year 2020 projections of Defense programs (other contributors too!)
Demand input from integrators, manufacturers, and suppliers would improve fidelity of demand forecast

Recent Assessments (AoA 2019)

- Demand for high-energy SEE testing is growing (projections only)





J. Franco & J. Ross, *2021 High-Energy Single-Event Effects (SEE) Testing Users Meeting* (slides)

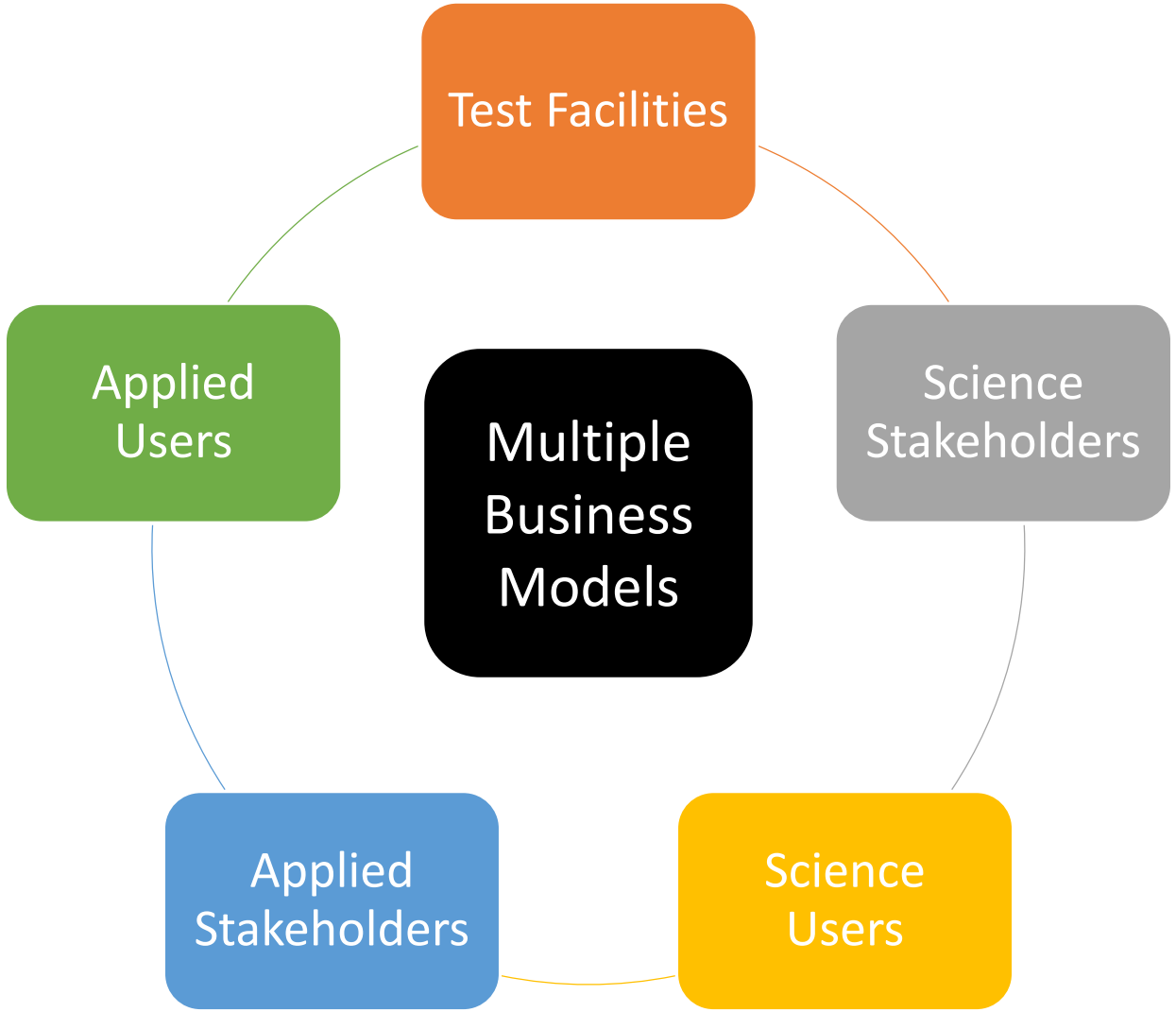
MITIGATIONS

What can we do to overcome challenges?

More Organizational Coordination

Most facilities have multiple user and stakeholder communities

SEE testers are often guests in facilities designed and built for science (e.g., nuclear physics)



Need to invest in facilities is clear, but the trade space is complex

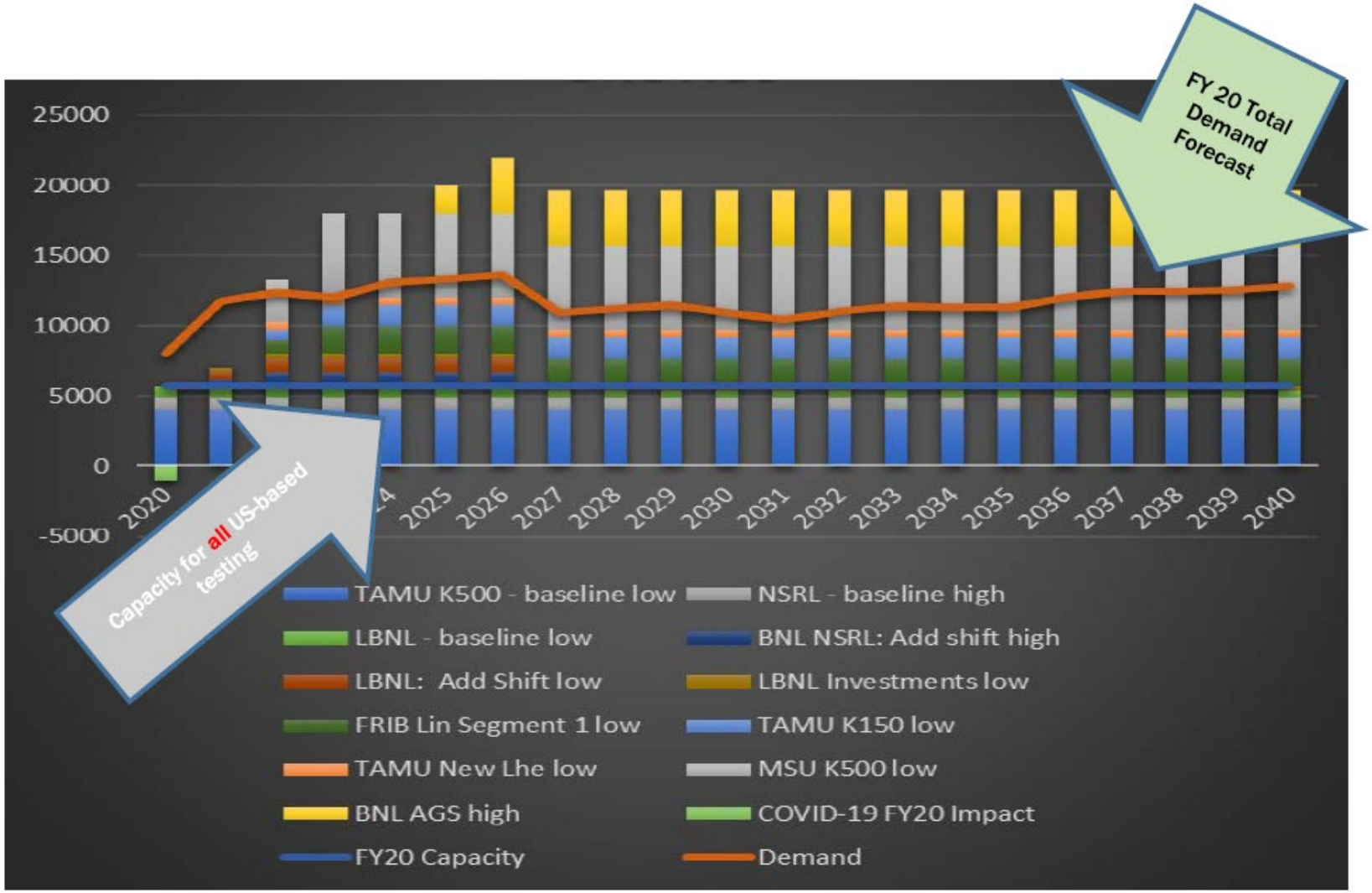
Unique time in the radiation effects community given planned investments & possibilities

Test Facility Sustainment & New Investments

- Utilize existing infrastructure to expand low-energy capacity
  - Repurpose available accelerator systems and leverage workforce, possibly gaining facilities more dedicated to SEE testing
  - Consider reliability investment for current accelerator systems to increase availability through better efficiency and less downtime
  - *Needs are immediate and investment proposals are forthcoming*
- Continue and accelerate studies for new high-energy capabilities
  - Understand demand evolution for high-energy SEE – harder to predict, but know it is coming
    - Development and utilization phasing are stretched out relative to low-energy investments
    - Requires more funding up front (vs. low-energy) and careful consideration of long-term operation and sustainment costs
  - *Needs are growing and proposals are being considered*

Capacity vs. Demand with Recommendations (AoA 2019)

- Solutions exist!
  - Range of paths to cover low- and high-energy gaps
  - Not all recommendations need to be pursued
- Investments in capacity and capabilities are evolving quickly and will play out over next several years



J. Franco & J. Ross, *2021 High-Energy Single-Event Effects (SEE) Testing Users Meeting* (slides)

Summary

- Heavy ion SEE testing is essential for robust space exploration, science, and technology capabilities
  - Essential part of the space industrial base
- Growing space economy and expanding mission objectives are driving demand and have created gaps in both capacity and capabilities
- Capacity and capability shortfall mitigations exist and require both sustained funding and coordination to execute successfully

- *Higher fidelity demand data, updated regularly, would help support investment and sustainment options (new way of thinking for radiation effects community)*
- *Same thoughts might be applicable to other types of SEE testing infrastructure*
- *While specifics may differ, general themes appear outside the U.S. too*

THANK YOU FOR YOUR ATTENTION

Acronyms

Abbreviation	Definition
3D	3-dimensional
AGS	Alternating Gradient Synchrotron
AoA	Analysis of Alternatives
ASIC	Application-Specific Integrated Circuit
BNL	Brookhaven National Laboratory
CART	Center for Advanced Radiation Technology
CCA	Circuit Card Assembly
CERN	European Organization for Nuclear Research
COVID	Coronavirus Disease
ETW	Electronics Technology Workshop
FPGA	Field Programmable Gate Array
FRIB	Facility for Rare Isotope Beams
FY	Fiscal Year
GANIL	Grand Accélérateur National d'Ions Lourds
GSFC	Goddard Space Flight Center
GSI	Gesellschaft für Schwerionenforschung
IC	Integrated Circuit
KVI	Kernfysisch Versneller Instituut

Abbreviation	Definition
LBNL	Lawrence Berkeley National Laboratory
MEAL	Mission, Environment, Application, and Lifetime
MSU	Michigan State University
NASA	National Aeronautics and Space Administration
NASEM	National Academies of Sciences, Engineering, and Medicine
NEPP	NASA Electronic Parts and Packaging (Program)
NSRL	NASA Space Radiation Laboratory
RADEF	RADiation Effects Facility
SEE	Single-Event Effects
SEE	Single-Event Effects
SRH	Strategic Radiation-Hardened
SRHEC	Strategic Radiation-Hardened Electronics Council
TAMU	Texas A&M University
TID	Total Ionizing Dose
TNID	Total Non-Ionizing Dose
TVdG	Tandem Van de Graaff
U.S.	United States
UCL	Université Catholique de Louvain