3rd TDAMM Workshop: Multidisciplinary Science in the Multimessenger Era

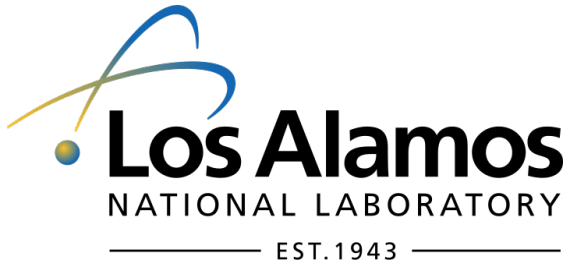
White paper will be presented to the AAAC at end of January

Eric Burns on behalf of

Chris Fryer (co-chair)

The SOC: Jennifer Andrews, Michela Negro, Francesca Civano, Julie McEnery, Aimee Hungerford, Michael Murillo, Hendrik Schatz, Carolyn Kuranz, Daniel Livescu, Chris Fontes, Amy Gall, Ed Thomas, Fan Guo, Jocelyn Read, Earl Scime

An approximately ~100 additional folks (we're sorting author/affiliations now)



Context

First Workshop, **Second Workshop**, **Third Workshop**

- The Astro 2020 Decadal prioritized Time-Domain And MultiMessenger (TDAMM) astrophysics
- There were two non-specific recommendations:
  - "**A suite of small and medium-scale ground and space-based observational facilities across the electromagnetic spectrum** to discover and characterize the brightness and spectra of transient sources as they appear and fade away."
  - "**Strong software and theoretical foundations** to numerically interpret the gravitational wave signals from merging compact objects to extract new physics in the extremes of density and gravity, and **ensure easy user access to the wealth of data on the dynamic universe and to model and interpret astronomical sources whose physical conditions cannot be replicated in laboratories on Earth.**"
- The TDAMM workshops foster discussions between the broader community and HQs on how to enable the best TDAMM science

3rd Workshop:
Multidisciplinary Workshop in the Multimessenger Era

Many transformational TDAMM questions must be approached using resources beyond any individual institution, facility, telescope, or agency.

- What are these transformational questions?
- What scientific disciplines are relevant?
- How can the necessary multidisciplinary studies be fostered?
  - How can we develop multidisciplinary scientists?

Motivation – National Research Council, 2003

1. What is Dark Matter?
2. **What is the Nature of Dark Energy?**
3. How Did the Universe Begin?
4. **Did Einstein Have the Last Word on Gravity?**
5. **What Are the Masses of the Neutrinos and How Have They Shaped the Evolution of the Universe?**
6. **How Do Cosmic Accelerators Work and What Are They Accelerating?**
7. Are Protons Unstable?
8. **What Are the New States of Matter at Exceedingly High Density and Temperature?**
9. Are There Additional Space-Time Dimensions?
10. **How Were the Elements from Iron to Uranium Made?**
11. **Is a New Theory of Matter and Light Needed at the Highest Energies?**

Motivation: Specific Goals

1. The Origin of the Elements
2. Cosmology
3. Extreme Matter
4. Black Hole Mass Extraction
5. Photon Splitting
6. Out of Equilibrium Physics

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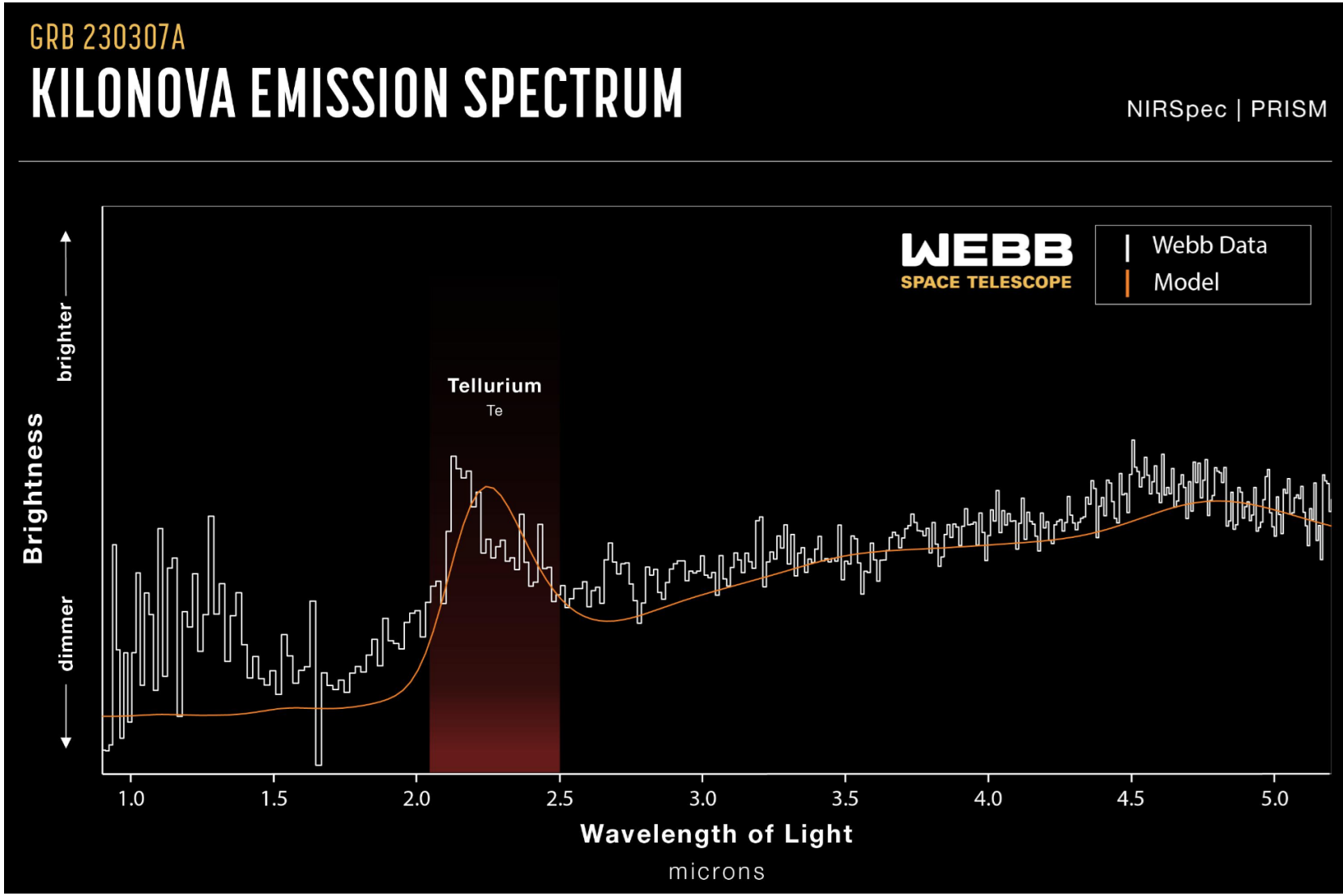

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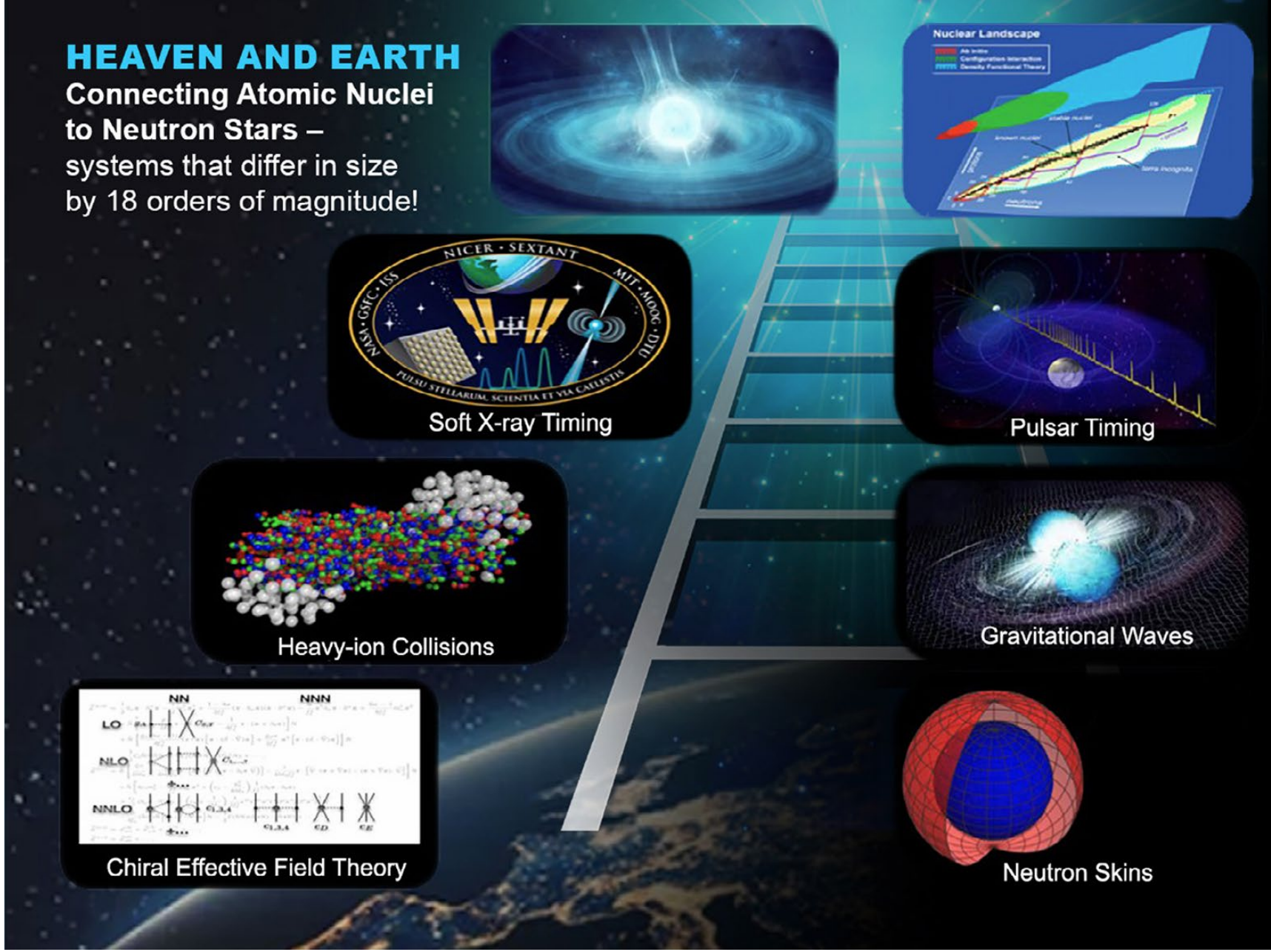


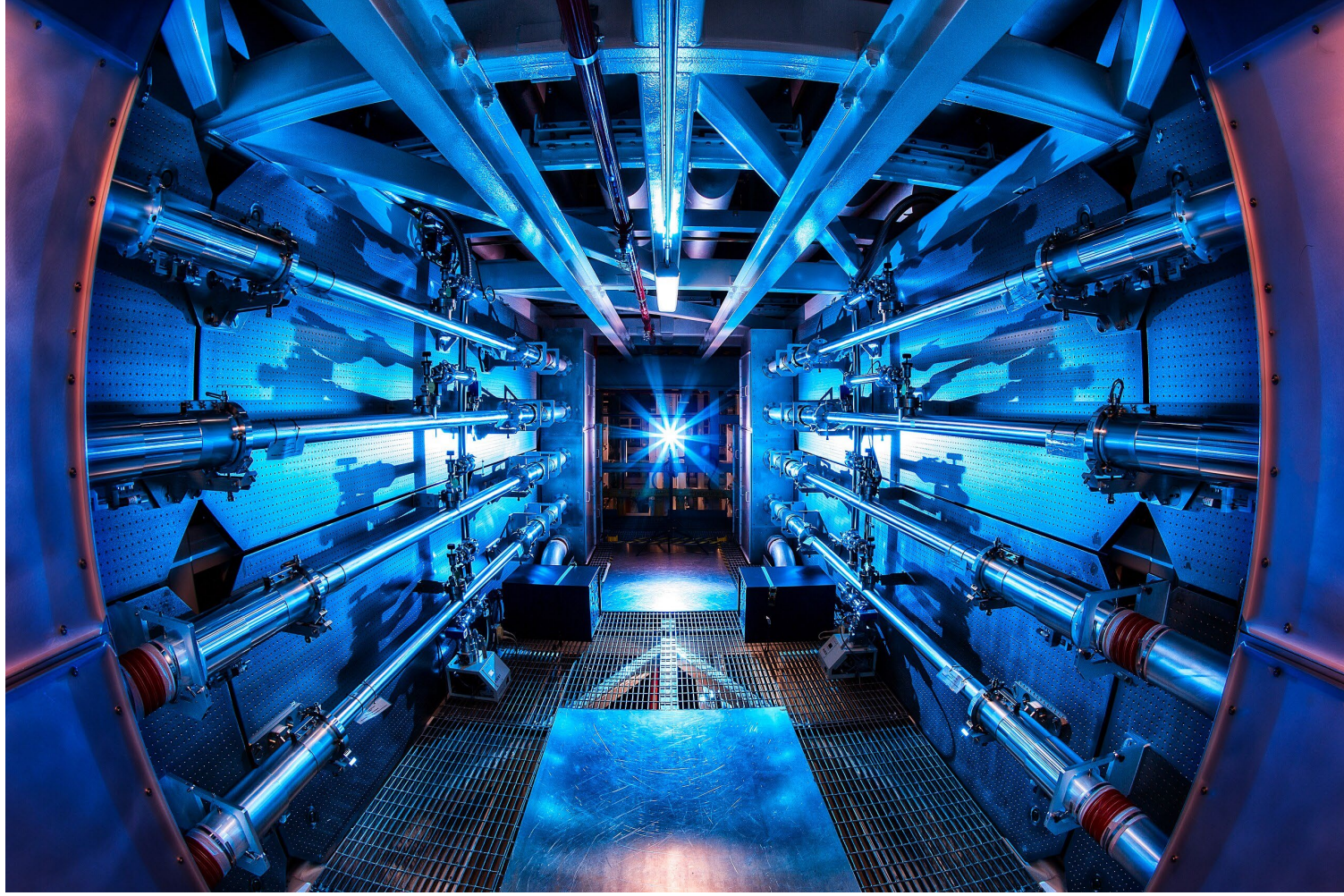
A Cosmic Density Ladder

Image credit: FRIB and Jorge Piekarewicz.

Disciplines

- Astrophysics
- Gravity
- Nuclear Science
- Plasma Physics
- Atomic Science
- Computation
- Fluid Dynamics, Turbulence
- **High Energy Density Physics**
- **Radiation Transport**

National Ignition Facility, LLNL



- Astrophysics is 20 years behind modern approaches in this fields
- Fields advanced by end-to-end approach by the National Nuclear Security Administration

Sources

- Novae
- Magnetars
- X-ray Binaries
- Fast Radio Bursts
- Gamma-Ray Bursts
- Neutron Star Mergers
- Active Galactic Nuclei
- Tidal Disruption Events
- Thermonuclear Supernovae
- Core-Collapse Supernovae

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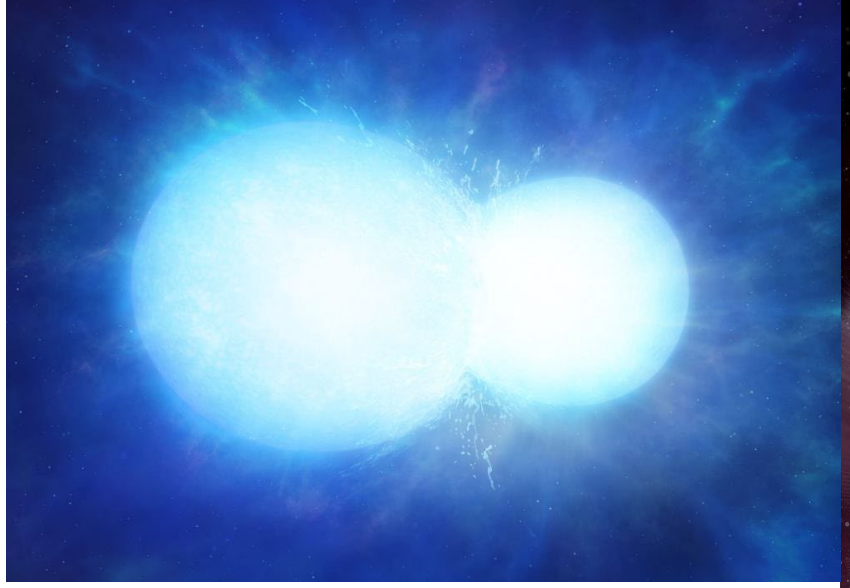
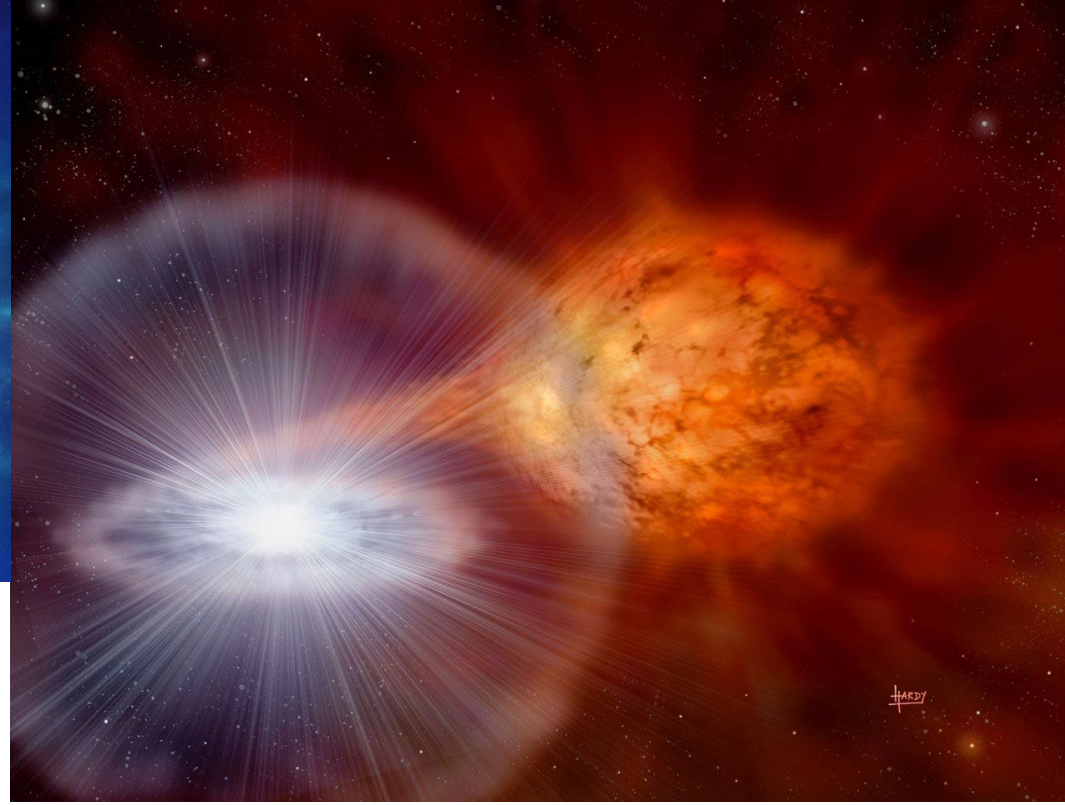


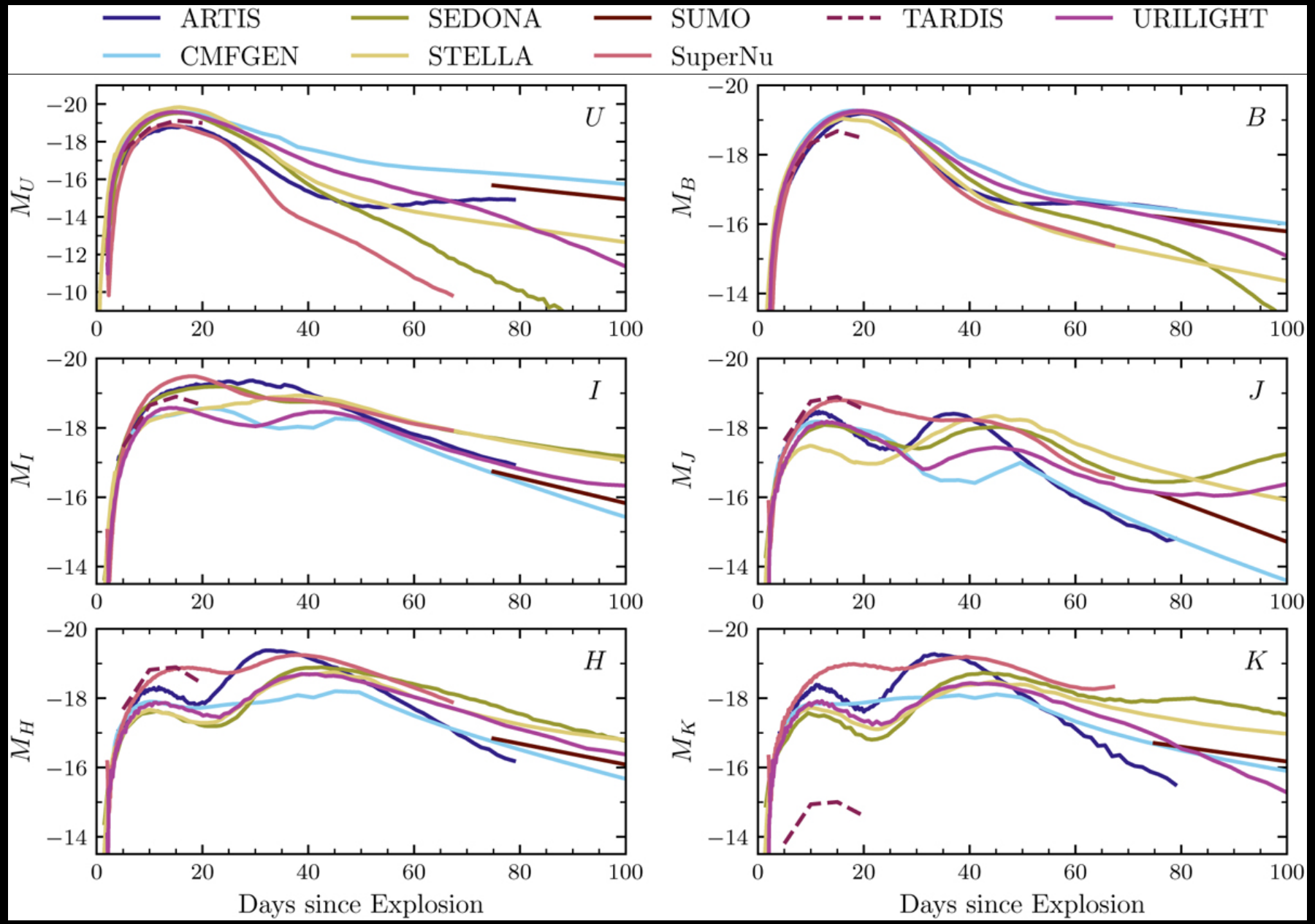
Credit: University of Warwick/Mark Garlick



Credit: David A. Hardy

- **COSI** will detect nuclear gamma-rays from a small number of novae and supernovae
- Making maximal use of this data requires an intentional integration of existing components

Core Collapse Supernovae



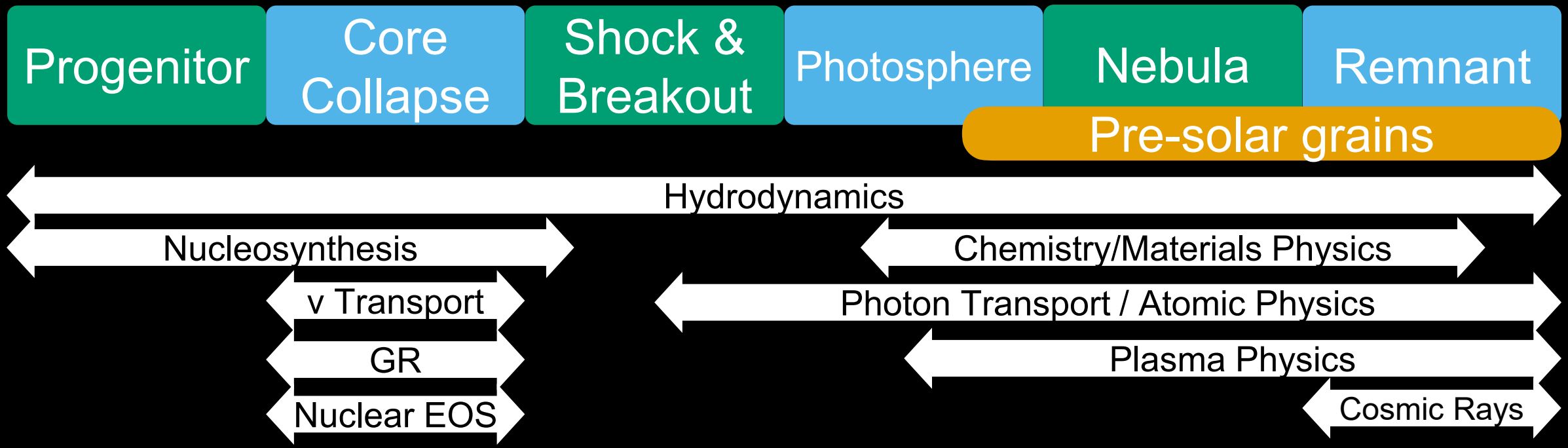
Blondin et al. 2022 A&A 448 A163

Code comparison

Photosphere

- Hydrodynamics
- Chemistry
- Photon Transport
- Plasma Physics
- Atomic Physics
- Materials Physics

Core Collapse Supernovae



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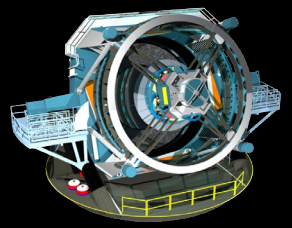
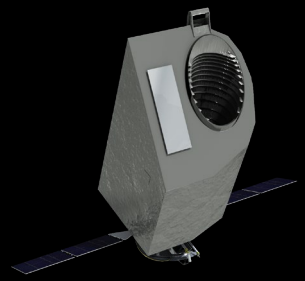
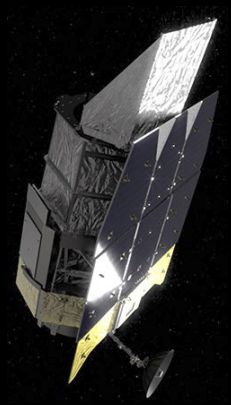
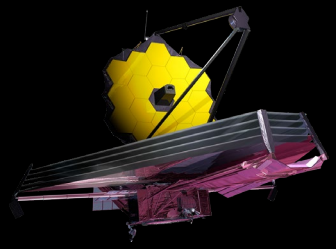


LIGO

DUNE







Progenitor	Core Collapse	Shock & Breakout	Photosphere	Nebula	Remnant

Pre-solar grains

Hydrodynamics

Nucleosynthesis

Chemistry/Materials Physics

ν Transport

Photon Transport / Atomic Physics

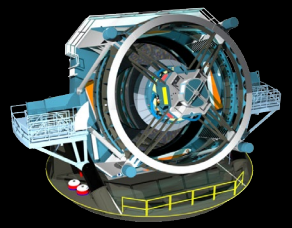
GR

Plasma Physics

Nuclear EOS

Cosmic Rays

Core Collapse Supernovae



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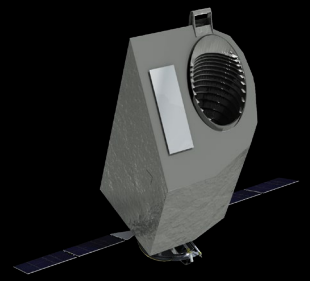

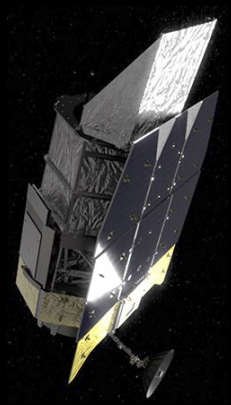

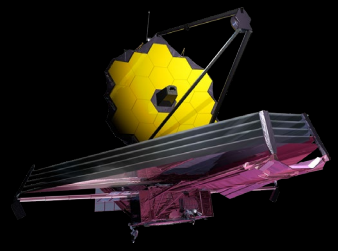

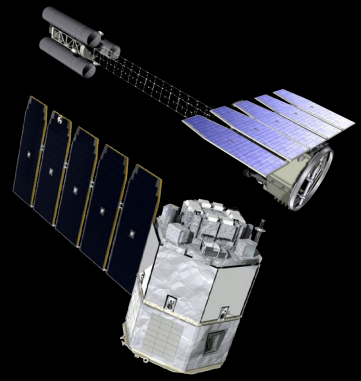

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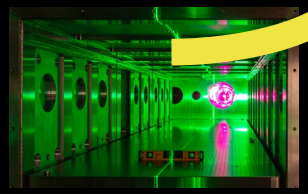

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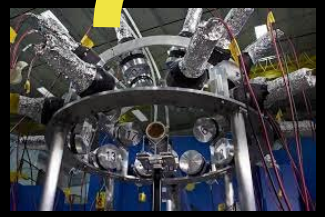
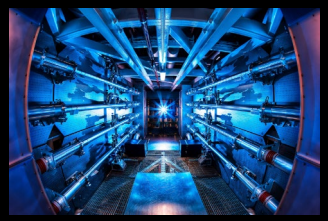
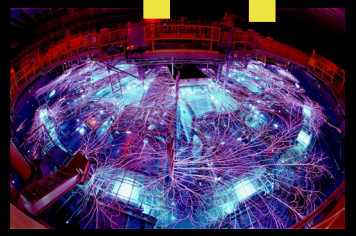


RHIC

relativistic heavy ion collider

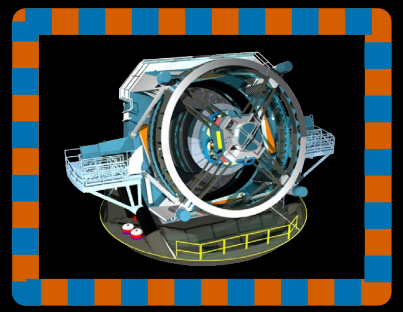




VERITAS

MPRL

Core Collapse Supernovae



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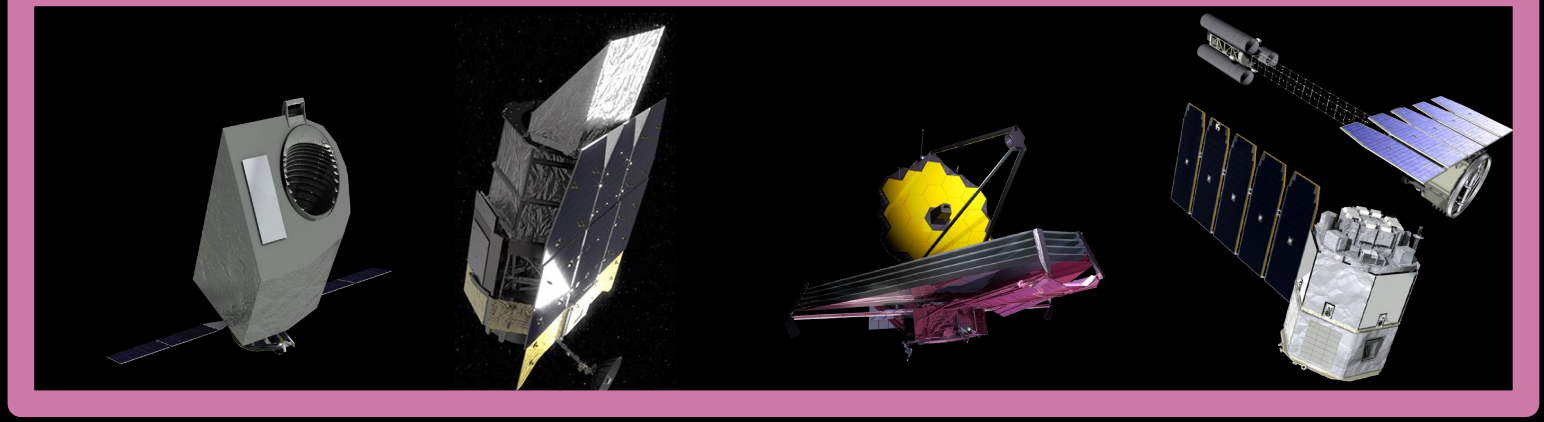

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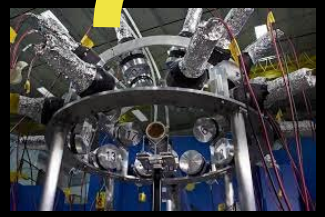

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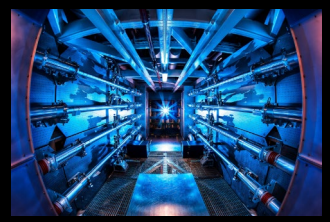

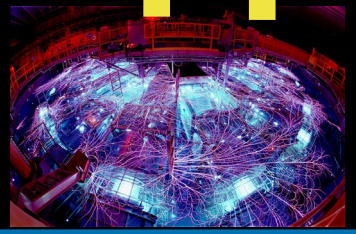

VERITAS

MPRL

Findings Summary

- **TDAMM science is at the intersection of physics and astronomy. No single agency can mount the effort needed to realize the great opportunities. DOE, NASA, and NSF are all deeply interested in this science, and each brings unique expertise to the enterprise.**
- Success requires a coordinated multi-agency, end-to-end approach
  - Maximizes scientific return and optimizes facility use in limited funding environments
  - Nearly all work is alignment and integration of existing components
  - Prioritize explosive transients as the most prepared sources for this approach
  - Requires new support for community building and organization
- This necessitates a strategic approach to TDAMM within NASA
  - The atomic science approach pioneered by XRISM should be adapted for UVEX, JWST
  - IXPE drives the need for novel numerical modeling approaches to magnetized plasmas
  - Success criterion for new missions should include maturation of theory, simulation
  - The Theoretical and Computational Astrophysics Networks scale is requires enhancement in funds (11% selection rate) and scope, as it is dwarfed (~x5) by similar NSF and DOE calls