muses

Modular Unified Solver of the Equation of State

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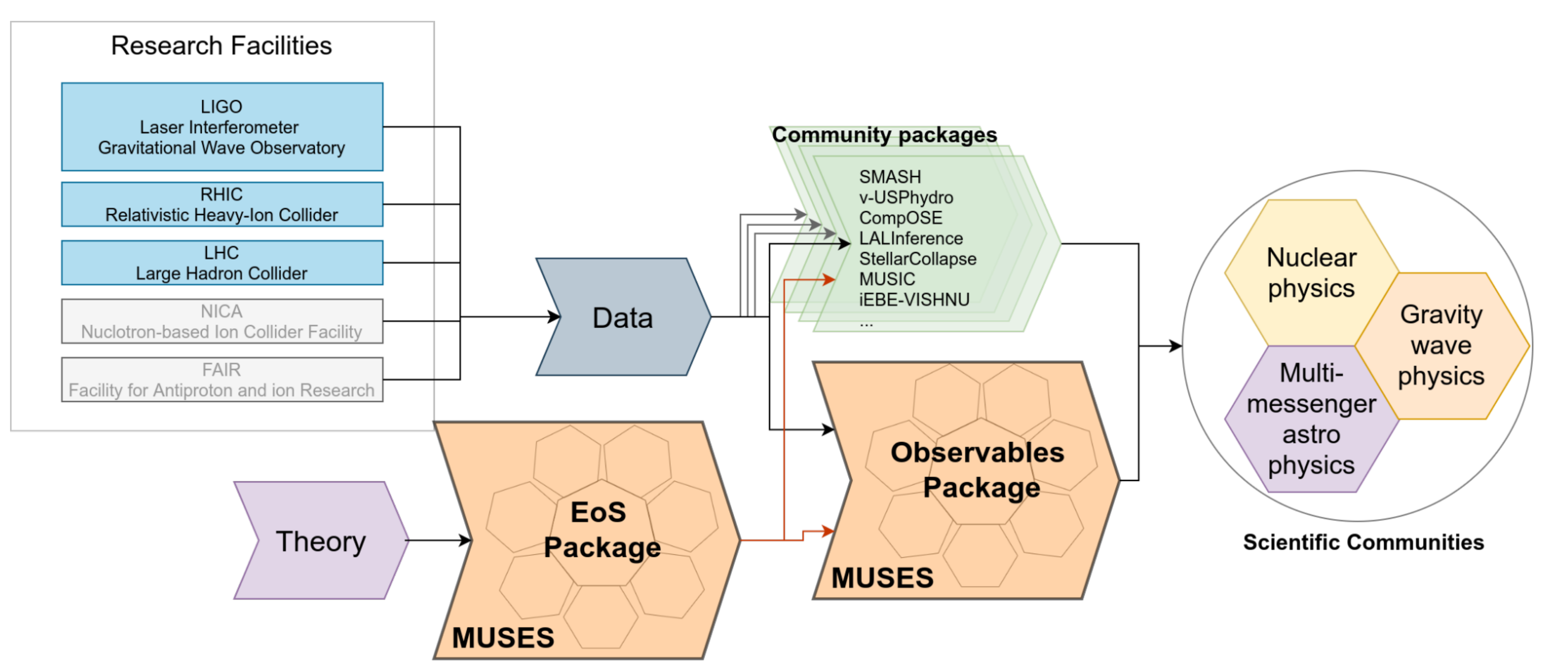
Background & Purpose

The recent detection of X-rays from hot spots on the surface of rotating **neutron stars** and the observation of the **gravitational waves** emitted when neutron stars collide hold the promise of revealing the mysteries of **nuclear astrophysical phenomena** in a previously inaccessible regime. Meanwhile, in the laboratory, **heavy-ion** collision experiments, akin to miniature neutron star mergers, can reveal complementary information about the properties of matter at **extreme temperatures and densities**.



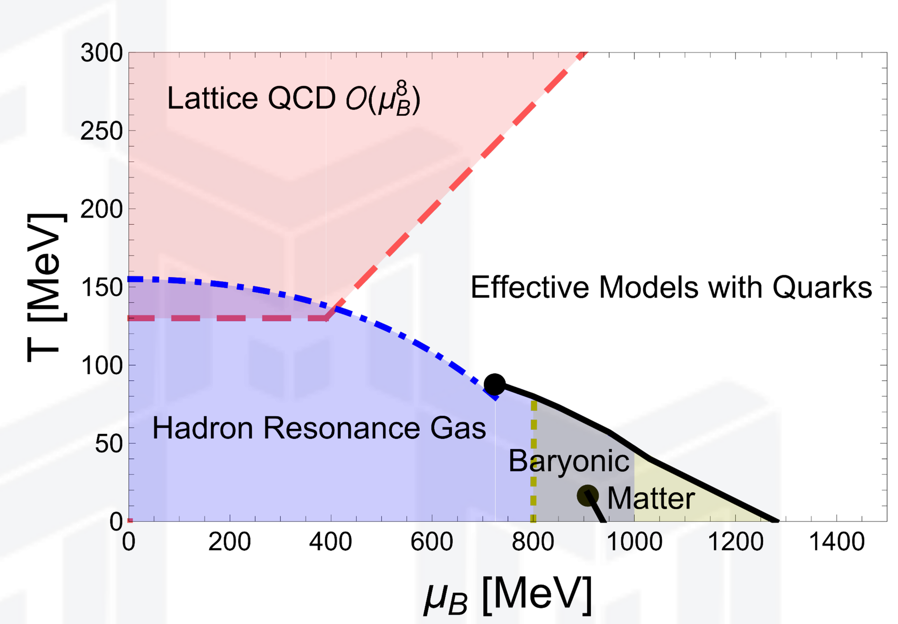
We are creating **a new, open cyberinfrastructure** that can rapidly and efficiently describe nuclear matter across vastly different densities and temperatures, allowing users to understand the nature of the building blocks of matter through **comparisons with data** from nuclear experiments (e.g. STAR), astrophysical observations (LIGO/NICER), and other international facilities.

MUSES will help answer fundamental physics questions including:

- What is the nature of matter at extreme pressures and temperatures?
- Under which conditions can we unlock quarks and gluons – the smallest building blocks of matter?
- Is there any place in the universe where quarks and gluons are the effective degrees of freedom instead of combining into larger structures?

Unification

While we know the theory that describes high-energy quantum chromodynamics (QCD), we cannot apply it directly to study matter at all the densities and temperatures needed to map the entire phase QCD diagram. Thus, a menagerie of effective models are used to describe different regimes.



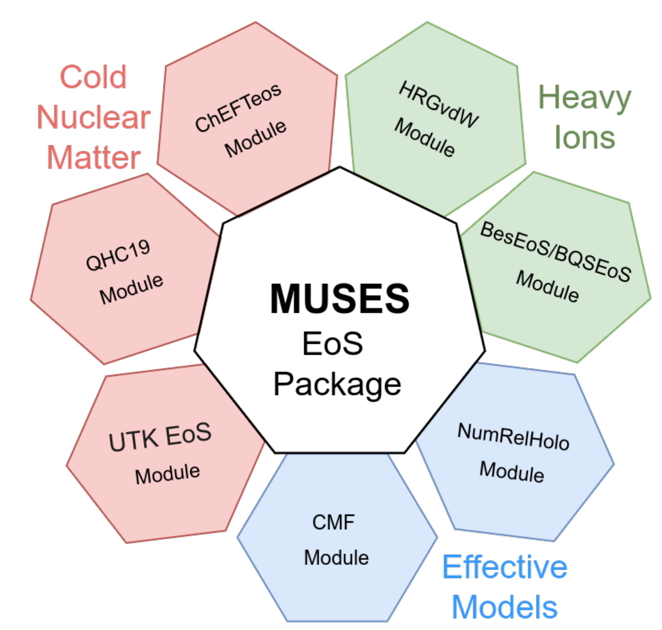
Schematic of the QCD phase diagram. Black dots mark critical points (liquid-gas and quark deconfinement).

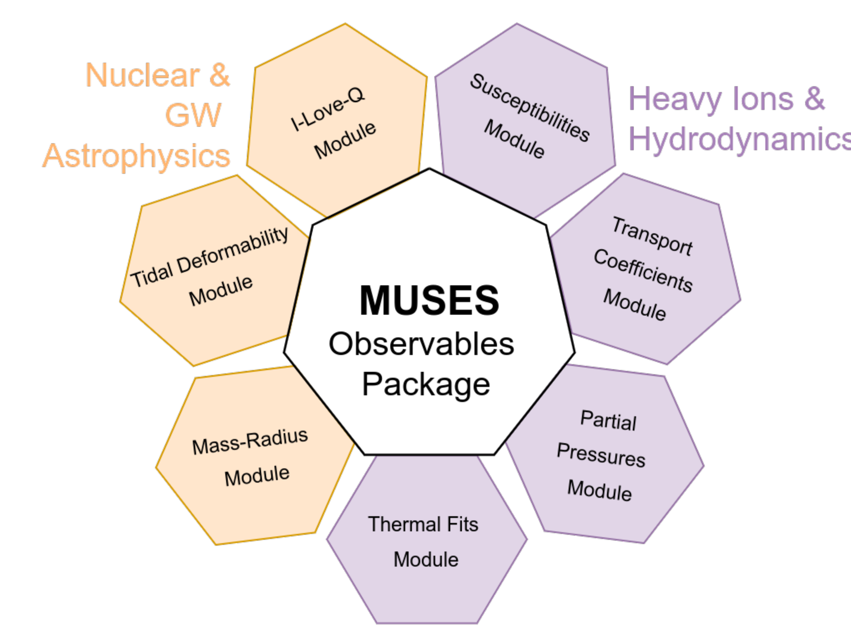
No universal model exists that smoothly matches across all of these different regimes, nor is there available open-source software that users can easily employ to study the entire QCD phase diagram.

MUSES aims to fill this need and enable breakthroughs, research innovation, and transformational capabilities in the many fields of our diverse user community.

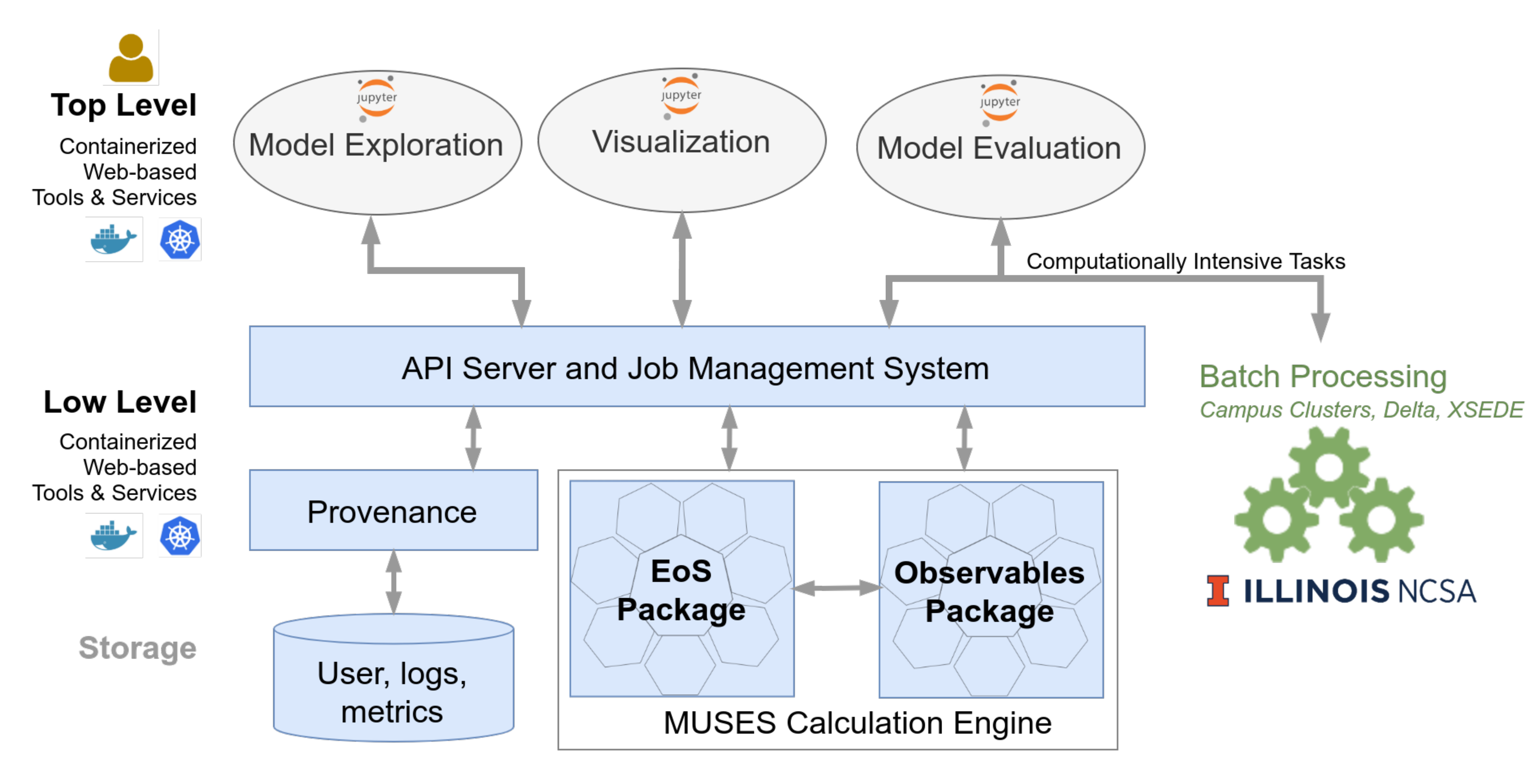
Modular calculation engine

We are creating modern, efficient and parallelizable code to generate equation-of-state modules in different regimes of density, pressure, and temperature in either 2, 3, or 4 dimensions.



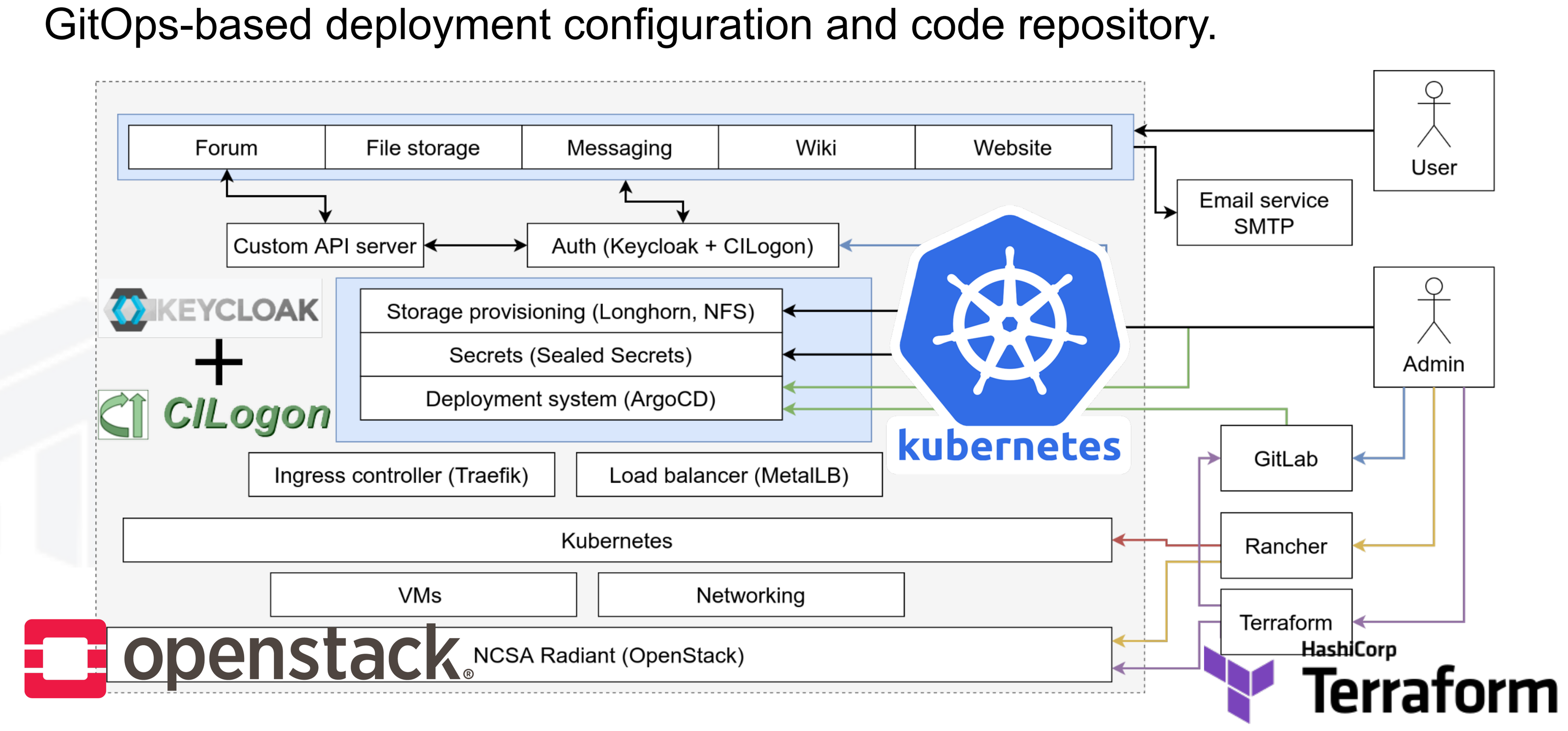


These modules are integrated into a single, standardized global calculation engine that allows the fast generation of equations-of-state across the entire phase diagram of quantum chromodynamics – the fundamental theory of strong interactions.



Deployment framework

The MUSES architecture is based on a portable, robust, standards-based deployment software stack. The foundation is infrastructure-as-code, using **Terraform** to provision virtual machines and networking apparatus on any **OpenStack-compatible** hosting platform, such as the current home of MUSES: the **NCSA Radiant cloud computing** platform. Applications and services are deployed on a **Kubernetes** cluster via a reproducible, GitOps-based deployment configuration and code repository.



Sustainability

The MUSES project should thrive beyond the duration of the NSF grant, and we are building an open source community to support the framework's continued development in a variety of ways:

Open source scientific code modules and deployment repositories: GitLab source code repos and projects provide fine-grained access control over code where desired and make publicly visible code development convenient.

Public forum for community engagement: We operate a Discourse forum at `https://forum.musesframework.io` that is open to the public and also used by collaborators.

Matrix for real-time discussion and inclusive engagement: The Matrix network is an open, decentralized protocol for online discussion gaining popularity among open source projects seeking to advance beyond IRC while avoiding proprietary silos like Slack. We run our own federated Matrix server and web client at `https://element.musesframework.io`

Identity and access management uses existing identity providers: Our single-sign-on authentication system is a self-hosted **Keycloak** server that leverages the **CILogon** service to connect users to an existing identity provider of their choice.

Portable domain name `musesframework.io` allows services to migrate between host institutions without disrupting service.

Collaboration

We are a growing international collaboration that includes **University of Illinois Urbana-Champaign, National Center for Supercomputing Applications, University of Houston, Kent State University**, and several other institutions

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