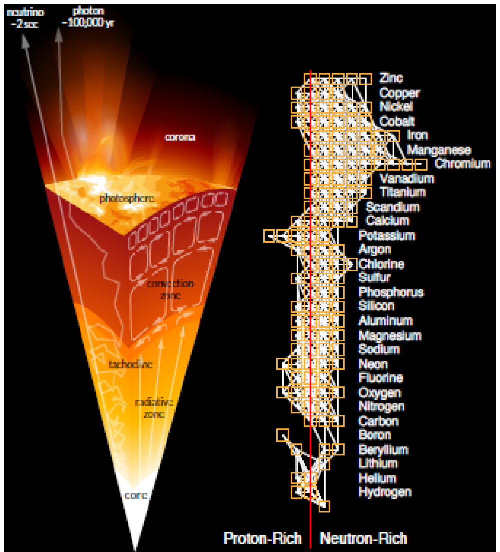
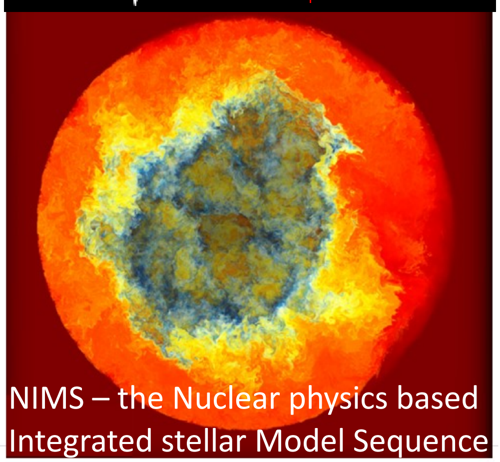
Dynamic Nuclear Burning in Stars

Questions – Status – Needs

Michael Wiescher
JINA – University of Notre Dame

The multiplicity of dynamic burning in stars




NIMS – the Nuclear physics based Integrated stellar Model Sequence

Quiescent burning

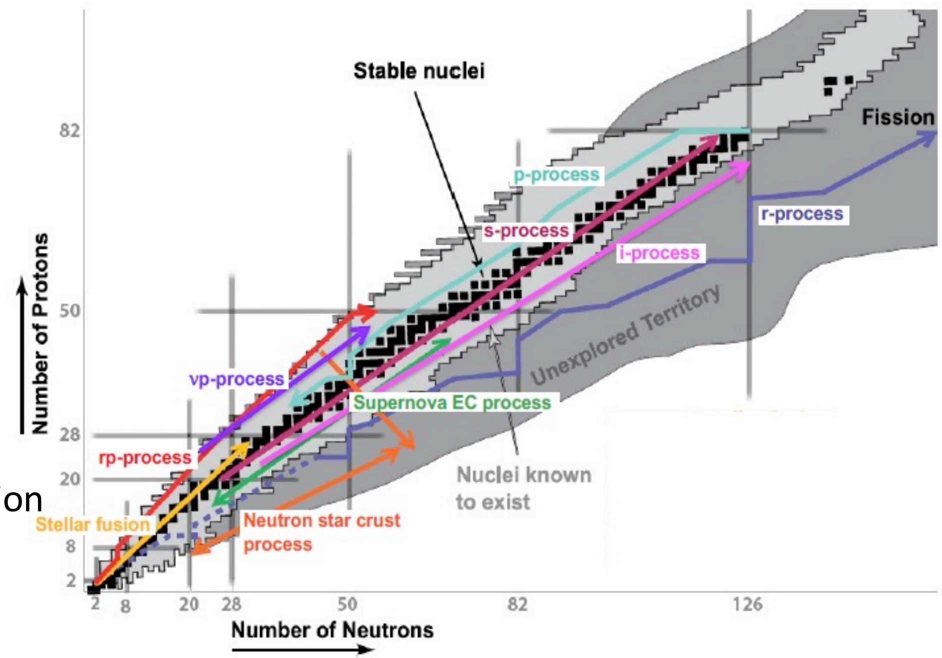
Hydrogen
Helium
Carbon
Neon
Oxygen
Silicon

Feeding explosive burning

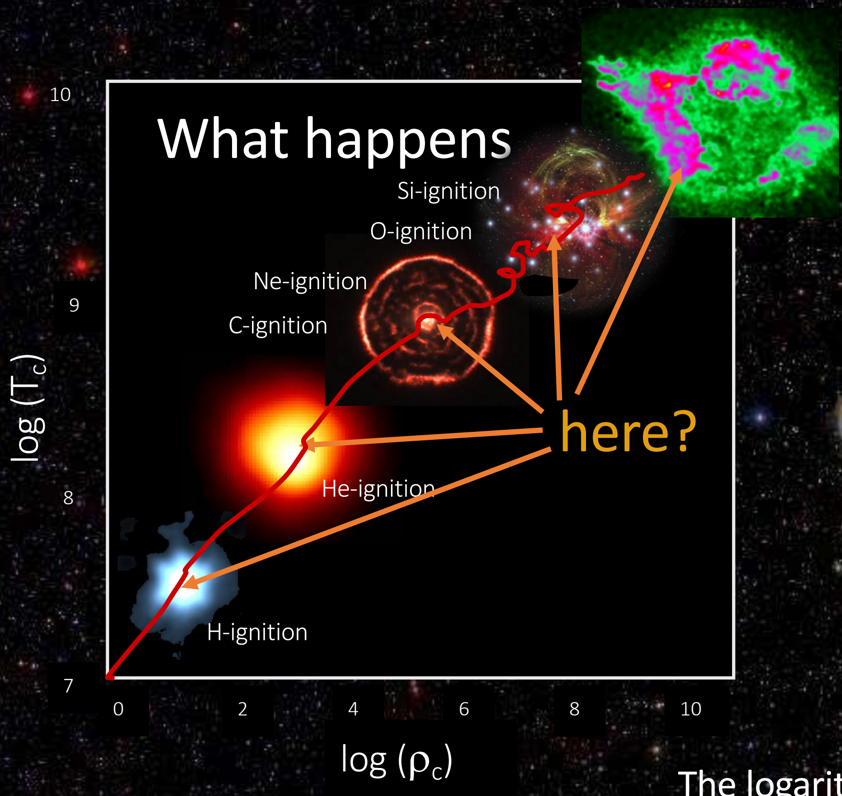
Accretion	Hydrogen Helium
Merger	Neutrons Helium Carbon
Collapse	Weak interaction Neutrons Helium

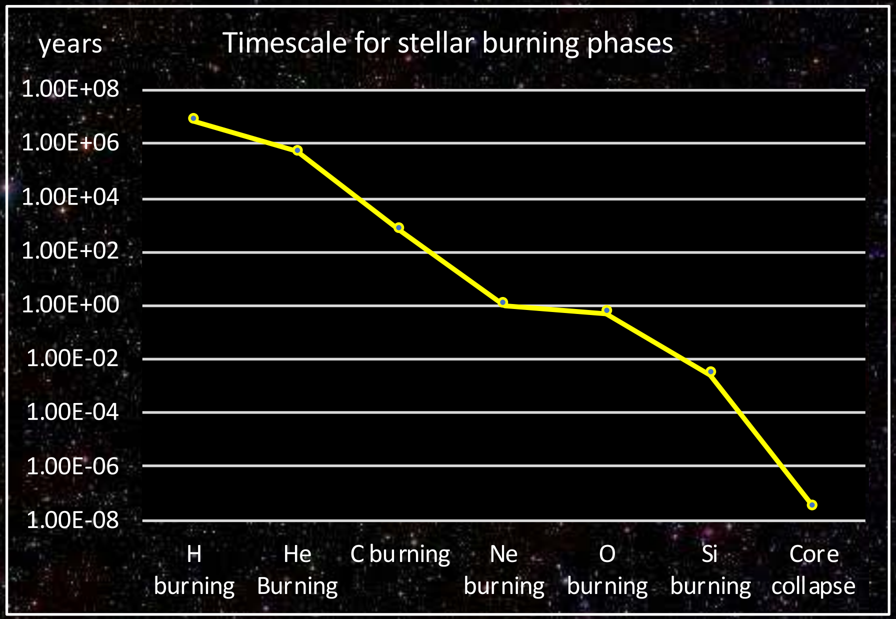
The foundation of nucleosynthesis!

Stars provide the fuel conditions of stellar explosions and define the conditions for ignition of explosion!



Stellar evolution for a 25 $M_\odot$ star





The logarithmic behavior of the timescale is directly correlated with the temperature and charge particle penetrability due to the Coulomb barrier!

Scientific Questions

Astrophysics:

- ➢ **Nuclear Reaction rates at stellar burning conditions - represented by the Gamow range!**
  - They determine all dynamic timescales of stars!
  - They determine the seed abundances for subsequent burning!
  - They determine the observational signatures!

Weak Interaction physics

- ➢ **Electron capture rates set conditions for the core collapse!**
  - Electron capture rates are fueling the core collapse!
  - Neutrino rates provide unique observables (sun)!

Nuclear Physics:

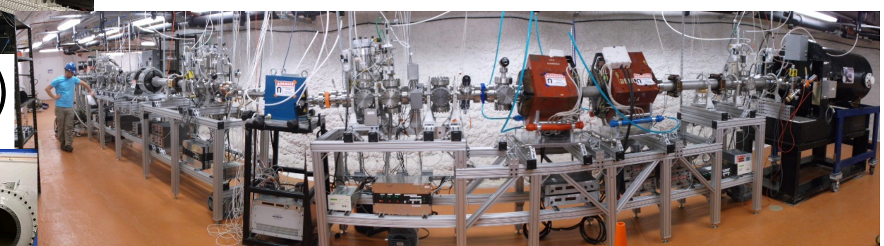
- ➢ **Low energy structure configurations impact the reaction rates at near threshold energies!**
  - Threshold effects due to the emergence of single particle, alpha cluster, carbon clusters?
  - Electron screening and other quantum effects neglected in reaction theory, emergent in plasma physics!

Major construction projects since the last LRP

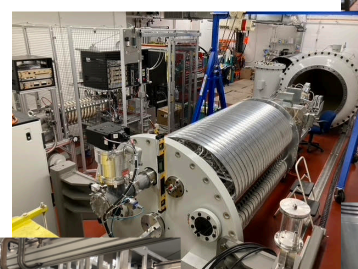
Instrumentation:

St. George is operating
(Dragon & ERNA)

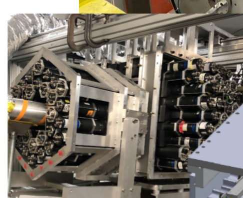
CASPAR at SURF is operating (back again in 2023)
(LUNA, JUNA)

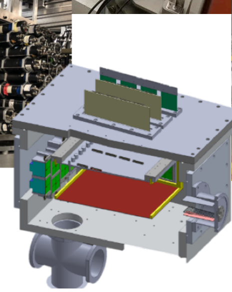


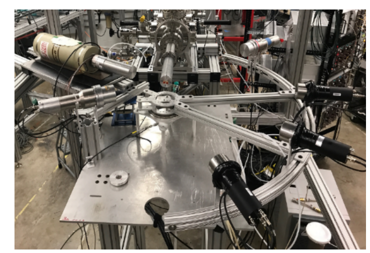
LENA upgrade to 2MV
(LUNA-MV)



Detector developments at
National Labs and Universities







THM and other indirect techniques

Major accomplishments since the last LRP

First Stars: Alpha induced reactions to by-pass A=5 and A=8 gap (Notre Dame, SD Mines)

Solar neutrino sources: new studies of ^{3}He(α,γ)^{7}Be, ^{7}Be(p,γ)^{8}B, (Ohio University)

^{14}N(p,γ)^{15}O($\beta^{+}\nu$) and ^{12}C(p,γ)^{13}N($\beta^{+}\nu$) reactions (Notre Dame, TUNL)

Stellar plasma aspects: light ion fusion at NIF and OMEGA, provide data on screening effects

Neutrino detector background: ^{13}C(α,n), ^{18}O(α,n) (Notre Dame, ORNL, Tennessee, Rutgers)

H-Burning: CNO reactions, NeNa reactions, Si-Ca reactions (novae) (MSU, Notre Dame, TUNL)

He-burning: ^{12}C(α,γ)^{16}O comprehensive R-matrix analysis (Notre Dame, HIγS)

Hoyle State ground state decay (Texas A&M)

Neutron sources: ^{13}C(α,n)^{16}O, ^{17,18}O(α,n)^{20}Ne, ^{22}Ne(α,n)^{25}Mg (Notre Dame, SD Mines, TUNL)

^{22}Ne+α THM studies (Texas A&M)

C-burning: ^{12}C+^{12}C low energy fusion studies, ^{12}C+^{12}C THM (Notre Dame, Texas A&M)

SN- Core collapse: weak interaction by systematic charge exchange reaction studies. (MSU)

Questions and opportunities for the next decade

The main question is for reliable low energy data and the reliability of the extrapolation of experimental data into the stellar energy range!

- Maintain scientific flexibility through the modernization and funding of small university labs to pursue direct measurements, developing innovative ideas such as THM, nuclear fluorescence, and other indirect techniques!
- Most important is the funding for new detector developments and purchases!
- **LRP 2015: "A high intensity underground accelerator would be essential for addressing the broad range of experimental questions associated with the nucleosynthesis in stars."**
- Underground accelerator? **Yes, but the train is leaving the station**, funding for participation in Europe or Asia will help to maintain the scientific role and impact of the US community!

- New effort in reaction theory - old is not bad, but it needs to implements new observations and discoveries of reaction features
- Are there and what are the threshold effects which seem to hamper low energy extrapolation? The coupling of accelerator, THM, and plasma data is essential!

strategy for existing and planned capabilities

Coordination with astrophysics theory community

JINA on the national scale (will be replaced by CeNAM)

IReNA on the international scale (up to 2024)

Successful collaboration with NuGRID on international scale

Coordination with nuclear theory community

First developments through IReNA and further pursued by CeNAM

Coordination of experimental efforts

Coupling of THM and direct reaction results

(better data overlap, improved reaction modeling)

Joining forces CASPAR, (JUNA), LUNA, and surface labs

(prioritization and optimization, collaboration)

Better coupling within the ARUNA effort!

what resources are needed to maintain a world-leadership position in the nuclear astrophysics of stars

- **International communication and collaboration** has to be maintained if not strengthened, IReNA gas been enormously successful with increasing participation, the JINA concept has been copied multiple times, but with JINA gone the initiative is moving to Europe and Asia. The US effort needs to be rebuilt on a strong collaborative level - CeNAM!
- **Underground accelerator?** An underground accelerator laboratory of novel design would be necessary to maintain if not regain US leadership. To maintain some scientific role and impact of the US community in the short term, bridge funding for participation in European or Asian efforts are needed!