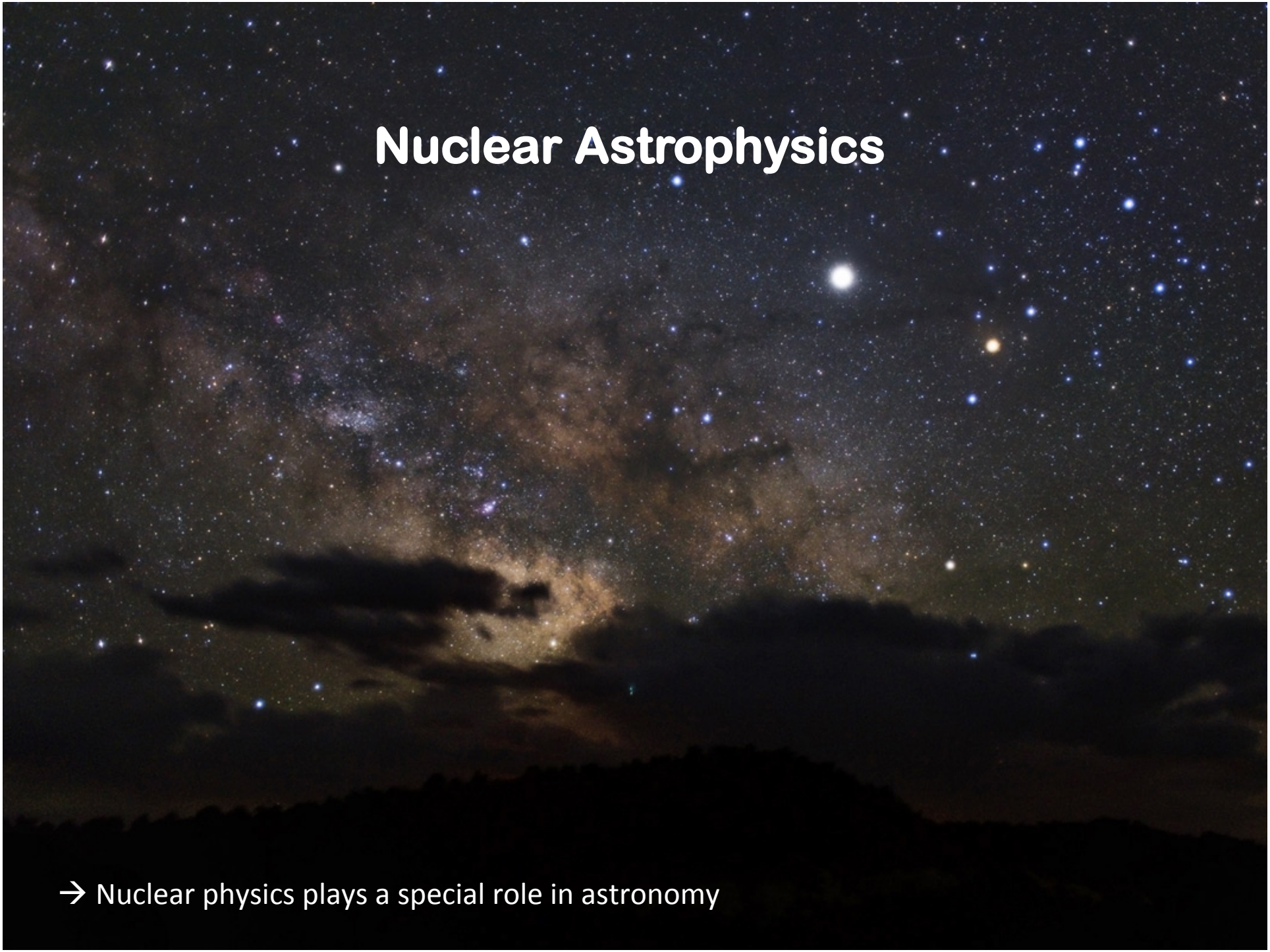
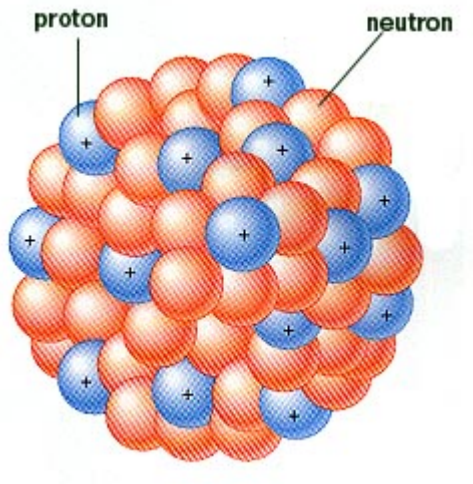

Nuclear Astrophysics
→ Nuclear physics plays a special role in astronomy

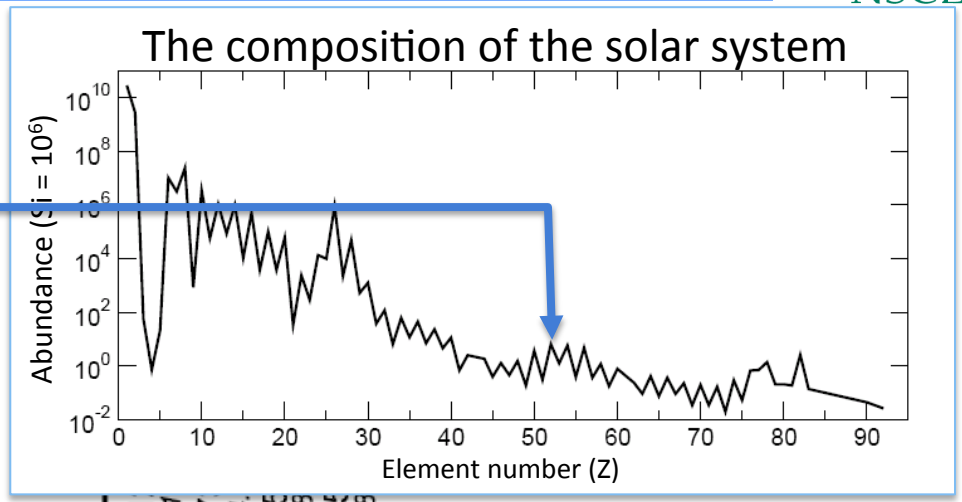
Nuclear structure: the DNA of chemical evolution (Woosley)

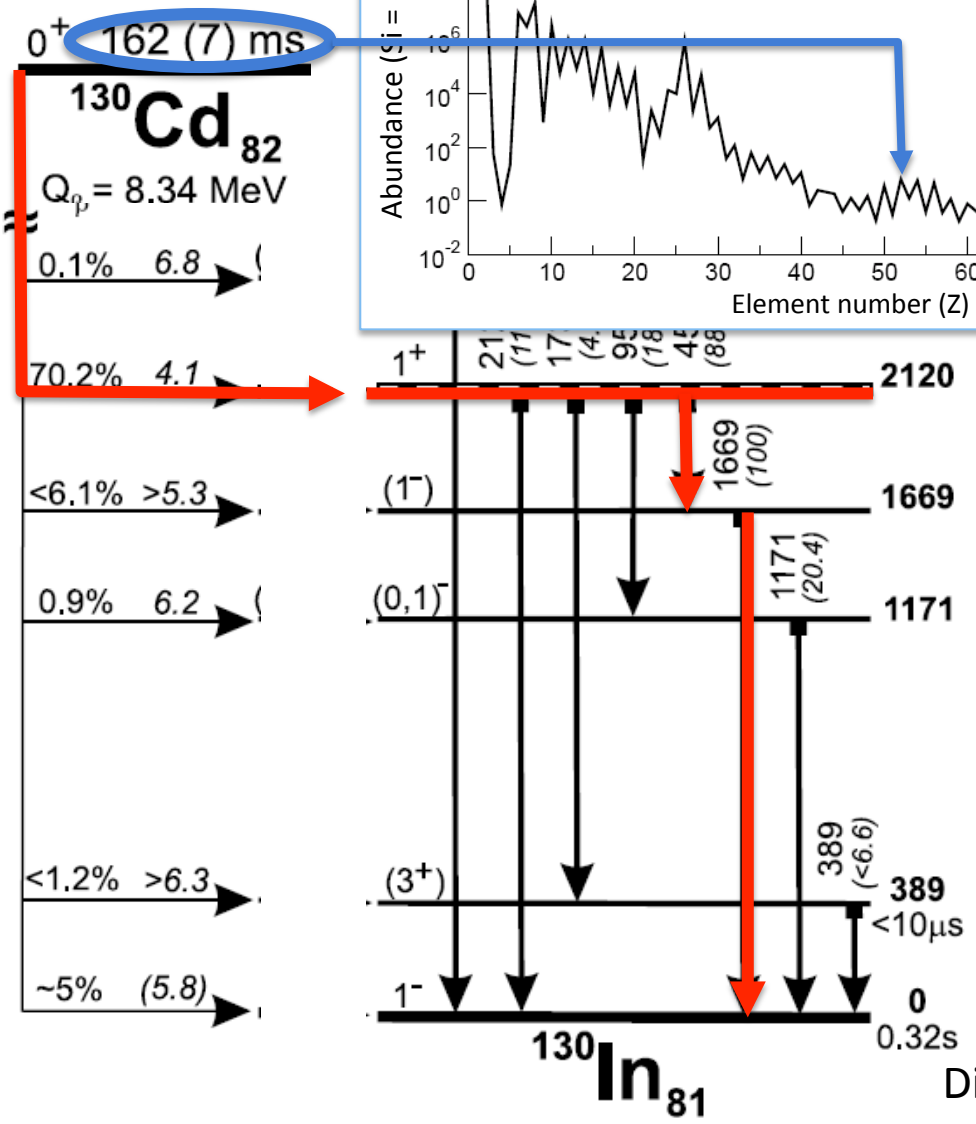
Nuclear structure



The DNA of the cosmos

The composition of the solar system

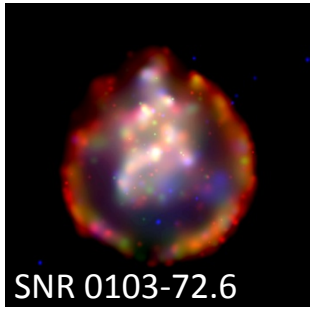




Dillmann et al. 2003

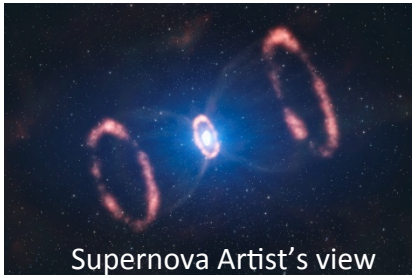
	3.3s	3.14s	4.2s	Pr128 2.85s	Pr129 30s	Pr130 40s	Pr131 1.51m	Pr132 1.6m	Pr133 6.5m	Pr134 17m	Pr135 24m	Pr136 13.1m	Pr137 1.28h	Pr1 2.12
58	Ce124 6s	Ce125 10.2s	Ce126 51s	Ce127 34s	Ce128 3.93m	Ce129 3.5m	Ce130 22.9m	Ce131 10.3m	Ce132 3.51h	Ce133 4.9h	Ce134 3.16d	Ce135 17.7h	Ce136 0.185	Ce1 1.43
57	La123 17s	La124 29.21s	La125 1.08m	La126 54s	La127 5.1m	La128 5.23m	La129 11.6m	La130 8.7m	La131 59m	La132 4.8h	La133 3.912h	La134 6.45m	La135 19.5h	La1 9.87
56	Ba122 1.95m	Ba123 2.7m	Ba124 11m	Ba125 3.5m	Ba126 1.667h	Ba127 12.7m	Ba128 2.43d	Ba129 2.23h	Ba130 0.106	Ba131 11.5d	Ba132 0.101	Ba133 10.52y	Ba134 2.417	Ba1 6.59
55	Cs121 2.583m	Cs122 3.7m	Cs123 5.88m	Cs124 30.8s	Cs125 46.7m	Cs126 1.64m	Cs127 6.25h	Cs128 3.62m	Cs129 1.336d	Cs130 29.21m	Cs131 9.689d	Cs132 6.48d	Cs133 100	Cs1 2.065
54	Xe120 46m	Xe121 40.1m	Xe122 20.1h	Xe123 2.08h	Xe124 0.09	Xe125 16.9h	Xe126 0.09	Xe127 36.4d	Xe128 1.92	Xe129 26.44	Xe130 4.08	Xe131 21.18	Xe132 26.89	Xe1 5.24
53	I 119 19.1m	I 120 1.36h	I 121 2.12h	I 122 3.63m	I 123 13.22h	I 124 4.176d	I 125 59.4d	I 126 12.93d	I 127 100	I 128 24.99m	I 129 1.57e+07y	I 130 12.36h	I 131 8.025d	I 13 2.29
52	Te118 6d	Te119 4.7d	Te120 0.09	Te121 154d	Te122 2.55	Te123 0.89	Te124 4.74	Te125 7.07	Te126 18.84	Te127 109d	Te128 31.74	Te129 33.6d	Te130 34.08	Te1 1.38
51	Sb117 2.8h	Sb118 5h	Sb119 1.591d	Sb120 5.76d	Sb121 57.21	Sb122 2.724d	Sb123 42.79	Sb124 60.2d	Sb125 2.759y	Sb126 12.35d	Sb127 3.85d	Sb128 9.01h	Sb129 4.4h	Sb1 39.5
50	Sn116 14.54	Sn117 7.68	Sn118 24.22	Sn119 8.59	Sn120 32.58	Sn121 43.9y	Sn122 4.63	Sn123 129.2d	Sn124 5.79	Sn125 9.64d	Sn126 2.3e+05y	Sn127 2.1h	Sn128 59.07m	Sn1 6.9
49	In115 95.71	In116 54.41m	In117 1.937h	In118 4.45m	In119 18m	In120 47.3s	In121 3.88m	In122 10.8s	In123 47.4s	In124 3.7s	In125 12.2s	In126 1.64s	In127 3.67s	In1 0.84
48	Cd114 28.73	Cd115 44.56d	Cd116 7.49	Cd117 3.36h	Cd118 50.3m	Cd119 2.69m	Cd120 50.8s	Cd121 13.5s	Cd122 5.24s	Cd123 2.1s	Cd124 1.25s	Cd125 0.65s	Cd126 0.515s	Cd1 0.43
47	Ag113 5.37h	Ag114 4.6s	Ag115 20m	Ag116 2.68m	Ag117 1.213m	Ag118 3.76s	Ag119 6s	Ag120 1.23s	Ag121 0.78s	Ag122 0.529s	Ag123 0.296s	Ag124 0.172s	Ag125 0.166s	Ag1 0.10
46	Pd112 21.03h	Pd113 1.55m	Pd114 2.42m	Pd115 50s	Pd116 11.8s	Pd117 4.3s	Pd118 1.9s	Pd119 0.92s	Pd120 0.5s	Pd121 1.44s	Pd122 0.519s	Pd123 0.23s	Pd124 0.0993s	Pd1 0.086
45	Rh111 11s	Rh112 6.8s	Rh113 2.8s	Rh114 1.85s	Rh115 0.99s	Rh116 0.68s	Rh117 0.44s	Rh118 0.266s	Rh119 0.467s	Rh120 0.202s	Rh121 0.101s	Rh122 0.0678s	Rh123 0.0517s	Rh1 0.045

Basic questions in Nuclear Astrophysics:

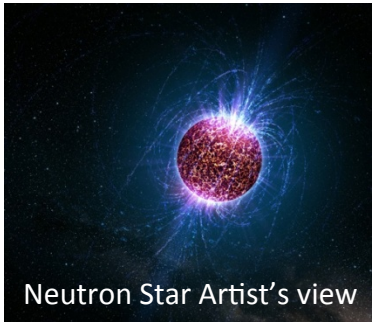

SNR 0103-72.6

1. What is the origin of the **elements**
   - origin of elements in our solar composition
   - Understanding compositional fingerprints of astrophysical events
   - Understanding compositional effects in stars, supernovae, neutron stars

2. How do stars and stellar explosions generate **energy**
   - Understand photon, neutrino emission
   - Understand how stars explode


Supernova Artist's view

3. What is the nature of **neutron stars**


Neutron Star Artist's view

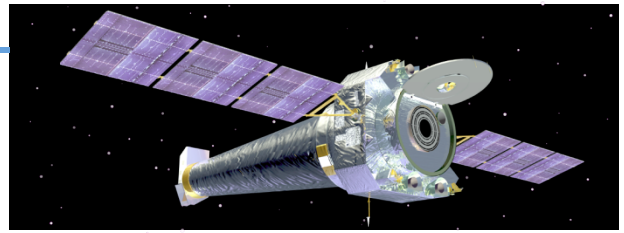
The Joint Institute for Nuclear Astrophysics

JINA a NSF Physics Frontiers Center – **www.jinaweb.org**

- **Identify and address the critical open questions and needs of the field**
- **Form an intellectual center for the field**
- **Overcome boundaries between astrophysics and nuclear physics and between theory and experiment**
- **Attract and educate young people**

Nuclear Physics Experiments

Astronomical Observations



Astrophysical Models

JINA

Core institutions:

- **Notre Dame**
- **MSU**
- **U. of Chicago**

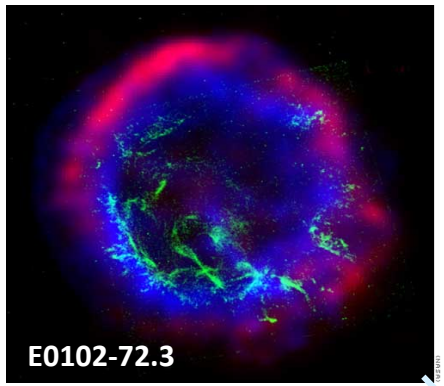
Associated:

ANL, ASU, Princeton
UCSB, UCSC, WMU
LANL, Victoria (Canada),
EMMI (Germany),
INPP Ohio, Minnesota
Munich Cluster (Germany),
MoCA Monash (Australia)

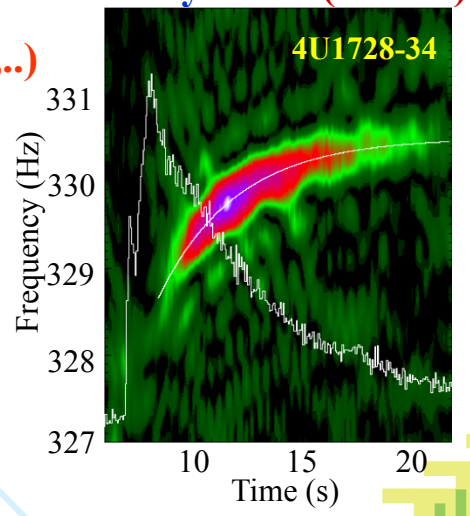
Nuclear Theory

http://www.jinaweb.org

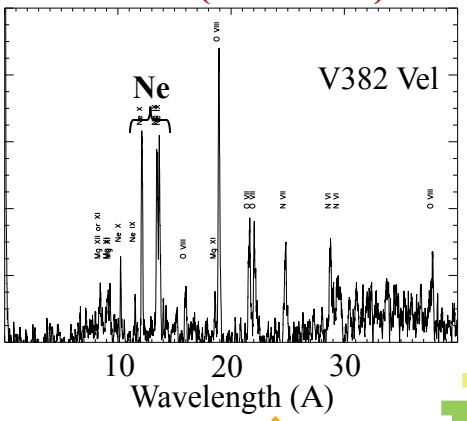
Supernova (Chandra,HST,..)



X-ray burst (RXTE)



Nova (Chandra)



Mass known
Half-life known
nothing known

p process

s-process

r process

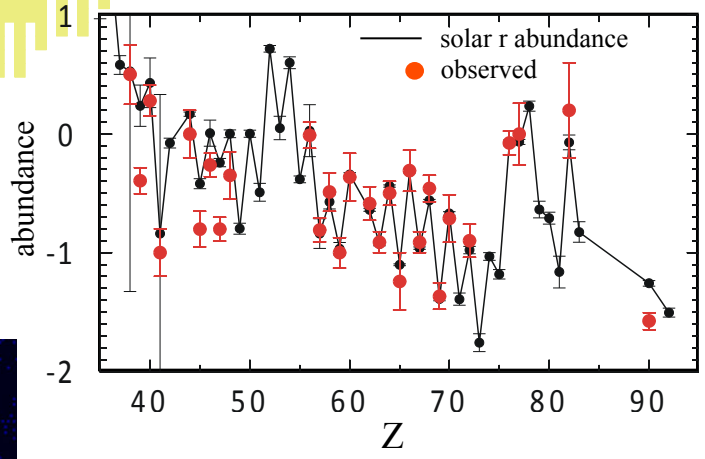
νp-process

rp process

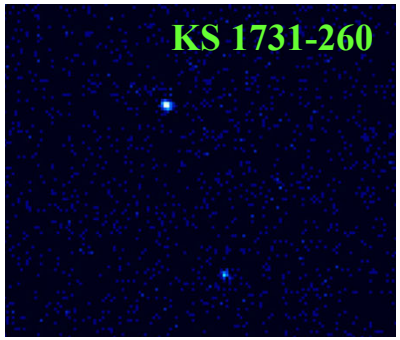
EC

Metal poor halo star (Keck, HST)

CS22892-052



n-Star (Chandra)



stellar burning

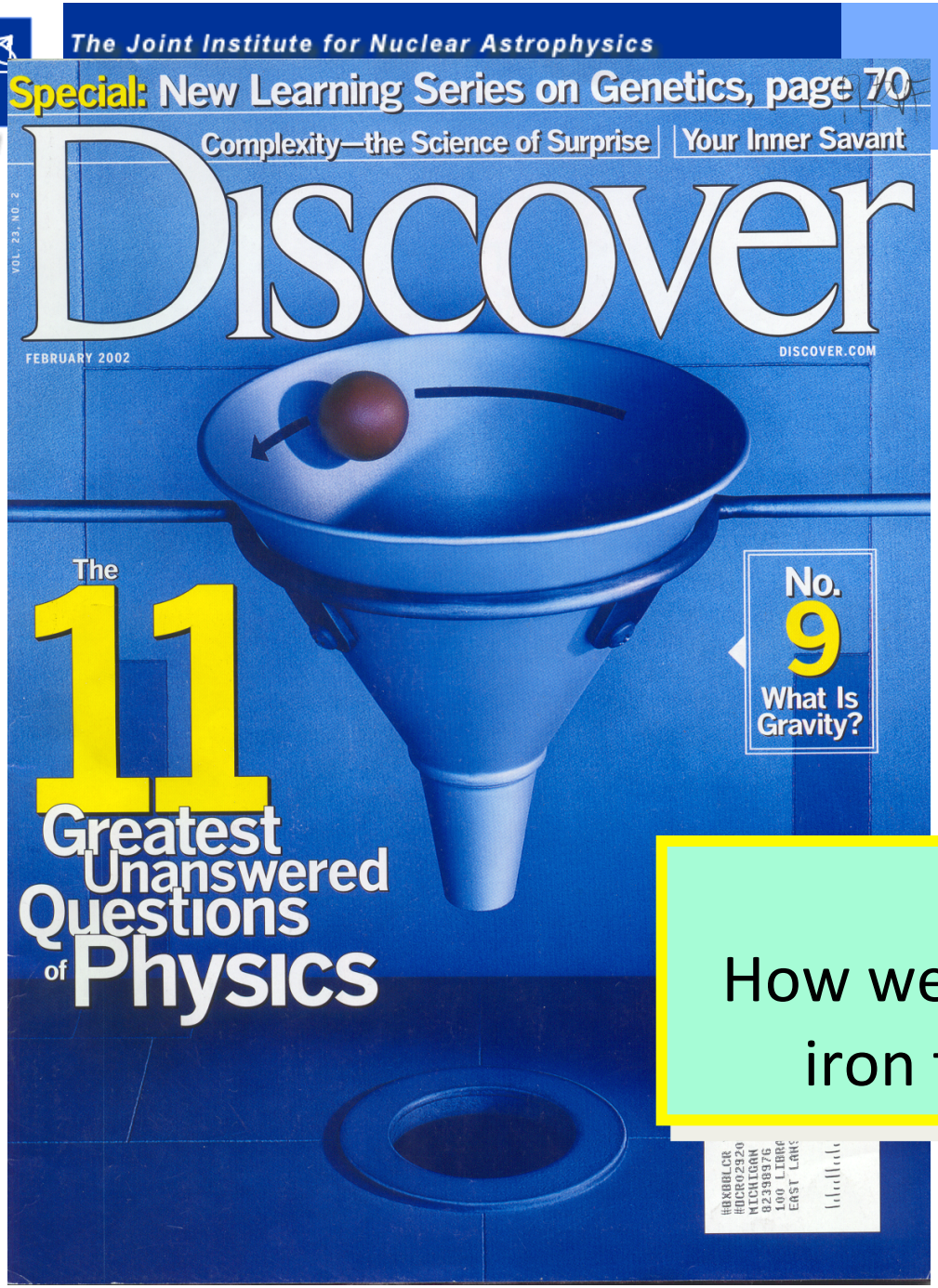
Big Bang

Cosmic Rays

Crust processes

and finally:

ν-process



Based on National Academy of Science Report

[Committee for the Physics of the Universe (CPU)]

Question 3

How were the elements from iron to uranium made ?

→ **"Old problems" Still unsolved !!!**

Summary

of the 2012 Nuclear Astrophysics Town Meeting

October 9-10, 2012 at the Westin, Detroit Metro Airport

Organized by the
Joint Institute for Nuclear Astrophysics

Local Organizers:
- Hendrik Schatz
- Sheila Balliet-Miles
- Linna Leslie
- Zach Meisel
- Fernando Montes
- Artemis Spyrou
- Chris Wrede

Sponsors:
- JINA
- National Superconducting Cyclotron Lab at Michigan State University
- European Physical Journal

Disclaimer:
- Opinions of community, not of JINA
- Preliminary and incomplete;
working groups not finished, personal impressions

Town Meeting

Twitter Feed

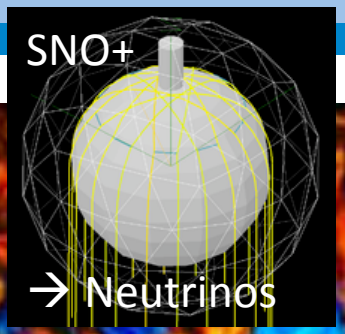
Follow:
@NucAstroTown12

- 150 Participants from Nuclear Physics, Astrophysics, and Astronomy
- 22 Plenary Talks, 13 2h working groups

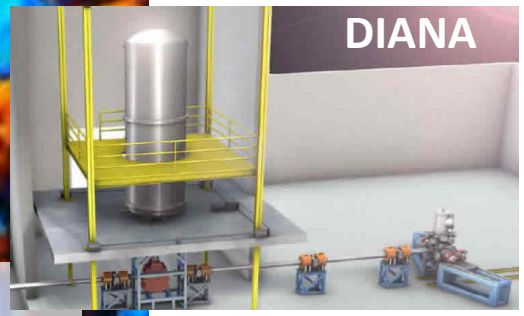
Goals: Generate a white paper with vision of the field in light of NP2010, ASTRO2010, .. (previous nuclear astrophysics white paper from 1999)

Stars

Multi-messenger Observations

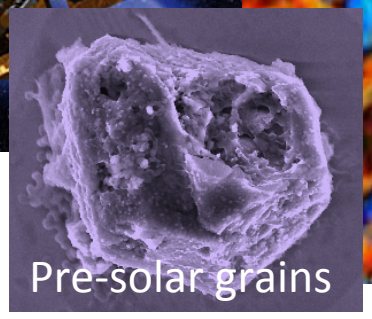


Accelerator Facilities



LENA, HIgS, StAna
LANSCE, FRANZ, nTOF
FRIB, CARIBU

Samples of stars



→ How do stars mix, rotate, and generate magnetic fields?

→ Which stars go supernova? Structure before it explodes?

→ What are the elements stars make? As a function of metallicity?

→ A new process? i-process

→ What is the sun's metallicity?

Theory:

- 3D Modeling
- Nuclear cross section extrapolation

Big Theme:

- Validation

Woodward

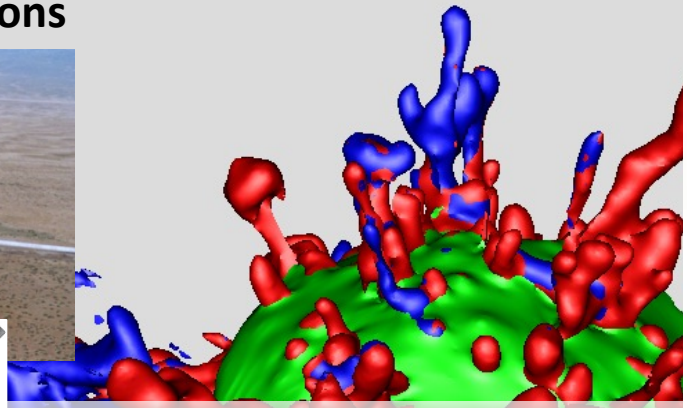
Core Collapse Supernovae

Multi-messenger Observations

SuperK, HALO, SNO+, …

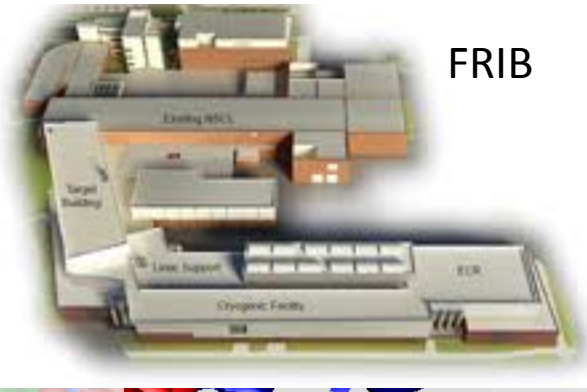
→ Elements in Stars

SDSS/APOGEE
AEGIS
LAMOST
GAIA
GALAH



→ What is the supernova mechanism?
→ What is the ν and grav. wave signal?
→ What are the sites of the r-processes? The LEPP process?
→ Which stars go supernova? GRB?

Accelerator Facilities



FRIB

CARIBU, TRIUMF
RIBF, FAIR

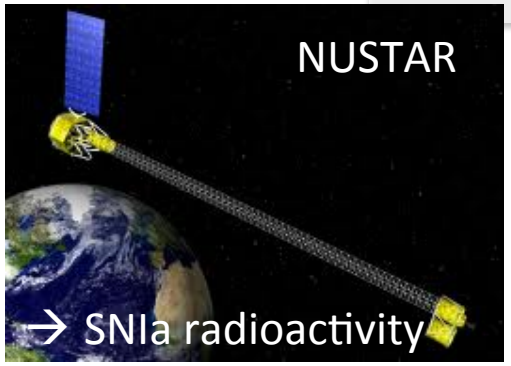
Astro Theory:
- Full 3D models
- Realistic progenitors

Nuclear Theory
- ν-oscillations understand & implement
- EOS
- r-process nuclei

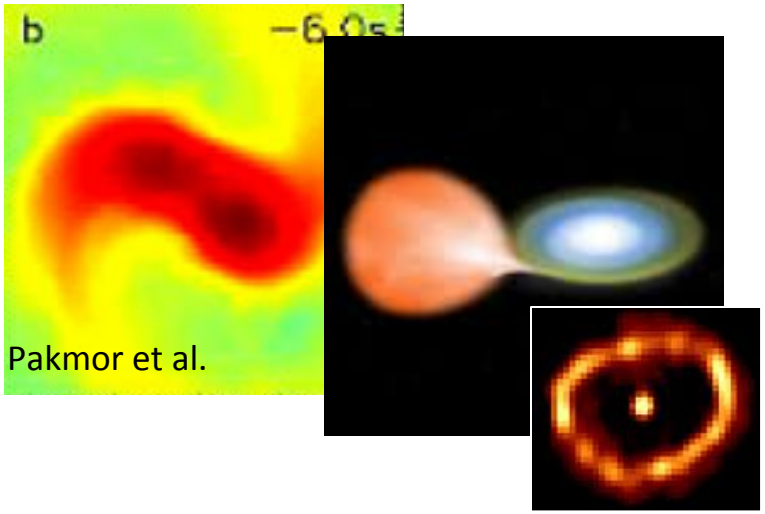
Novae and Ia Supernovae

→ What are the progenitors of type Ia?
→ What phenomena occur on accreting white dwarfs? Novae, type Ia, … ?
→ Nucleosynthesis contribution?
→ White dwarf masses of Novae? (LSST)

Multi-messenger Observations



ASTRO-H



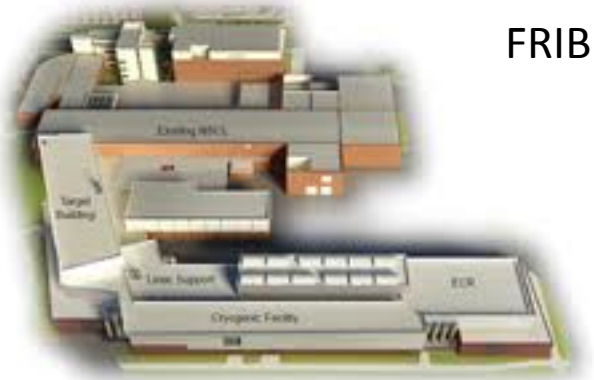
LSST

PTF

→ New types of explosions

GMT, JWST
IRTF, VLT, Gemini, Subaru
→ SN Ia composition (also IR !)

Accelerator Facilities

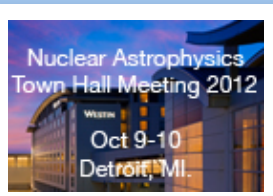


FRIB

TRIUMF
For weak rates also FAIR/RIBF
RCNP, TU Tandem
LENA, StAna, ATLAS, …

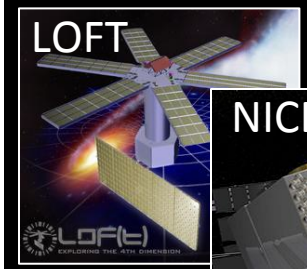
Astro Theory:
- Use nucleosynthesis as probe of ignition and progenitors
- Realistic progenitors
- Multi-D models

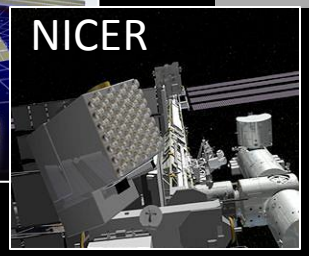
Nuclear Theory
- Electron capture rates



Neutron stars

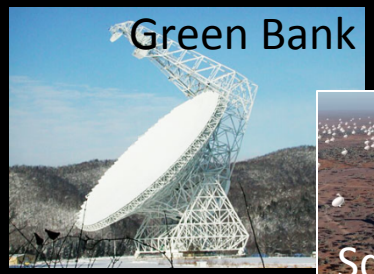
Multi-messenger Observations

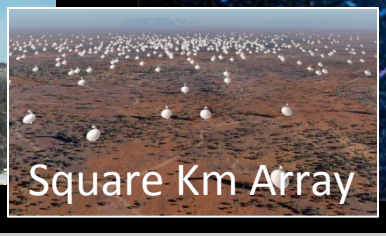




X-rays
→ thermal
→ radii

RXTE, XMM, Chandra, Swift, ASTROSAT
INTEGRAL, MINBAR archive





Radio
→ pulsars, masses

- → What are the properties of cold dense matter? What is its maximum density?
- → How can we determine Radii, M&R, crust properties from observations?
- → What powers superbursts?
- → Origin of burst oscillations?
- → Are NS Mergers GRBs? r-process site?

Accelerator Facilities

FRIB

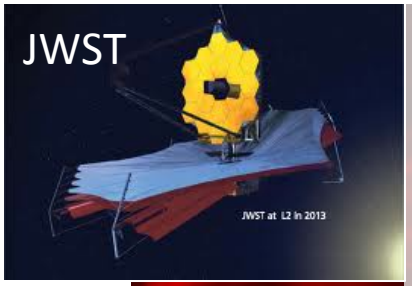
TRIUMF EOS: FRIB,RIBF,FAIR

Astro Theory:
- Realistic NS mergers
- 2D/3D X-ray bursts
- X-ray burst templates For parameter range
- Crust models

Nuclear Theory
- Crust nuclear physics
- EOS constraints (symmetry energy)

Big Bang, First Stars, and Chemical Evolution

High z Observations



→ What is the chemical evolution of Li, F, Ti, ^{15}N, O-Na, r-process ?
→ What are the first stars like?
→ How did dwarf galaxies evolve?
→ Big Bang: Is there primordial ^{6}Li? search for signatures beyond SBB

Nuclear physics:
For reliable predictions of nucleosynthesis yields of:
- First stars, other stars
- Ia Supernovae
- Core collapse Supernovae
- Low mass stars
- Neurton star mergers

Near field Observations

SDSS/APOGEE
AEGIS
LAMOST
GAIA
GALAH

Astro Theory:
- Nucleosynthesis of first stars
- Better GCE models
- Nucleosynthesis grids
- Chemistry/Opacities at high density

Summary

Observatories:

Key point: multi messenger

Optical: Giant Magellan Telescope, spectrograph

UV spectroscopy capability

X-ray Next Gen.: LOFT, …

γ-ray: NUSTAR, next γ-ray telescope?

Radio: GBT, Square Kilometer Array

GW: LIGO – GW networks

IR: IRTF

ν-detectors

Accelerators:

Unique capabilities of FRIB

- In many presentations, very broad impact
- FRIB + SECAR only real chance for a major step in measurements of reaction rates on unstable nuclei

Multi beam:

[Underground] stable beams (DIANA), γ-beams, neutron beams, ν-beams

Computing/Theory:

Multi-D is path forward across field

- People to adapt codes so they can run at forefront of computing
- Open source
- Make nuclear theory progress applicable to astrophysics

Centers: **Need for centers** (JINA)

- Connect subfields – data exchange
- Enable multi-messenger, multi-beam multi-disciplinary approaches needed for the future
- Voice for the field