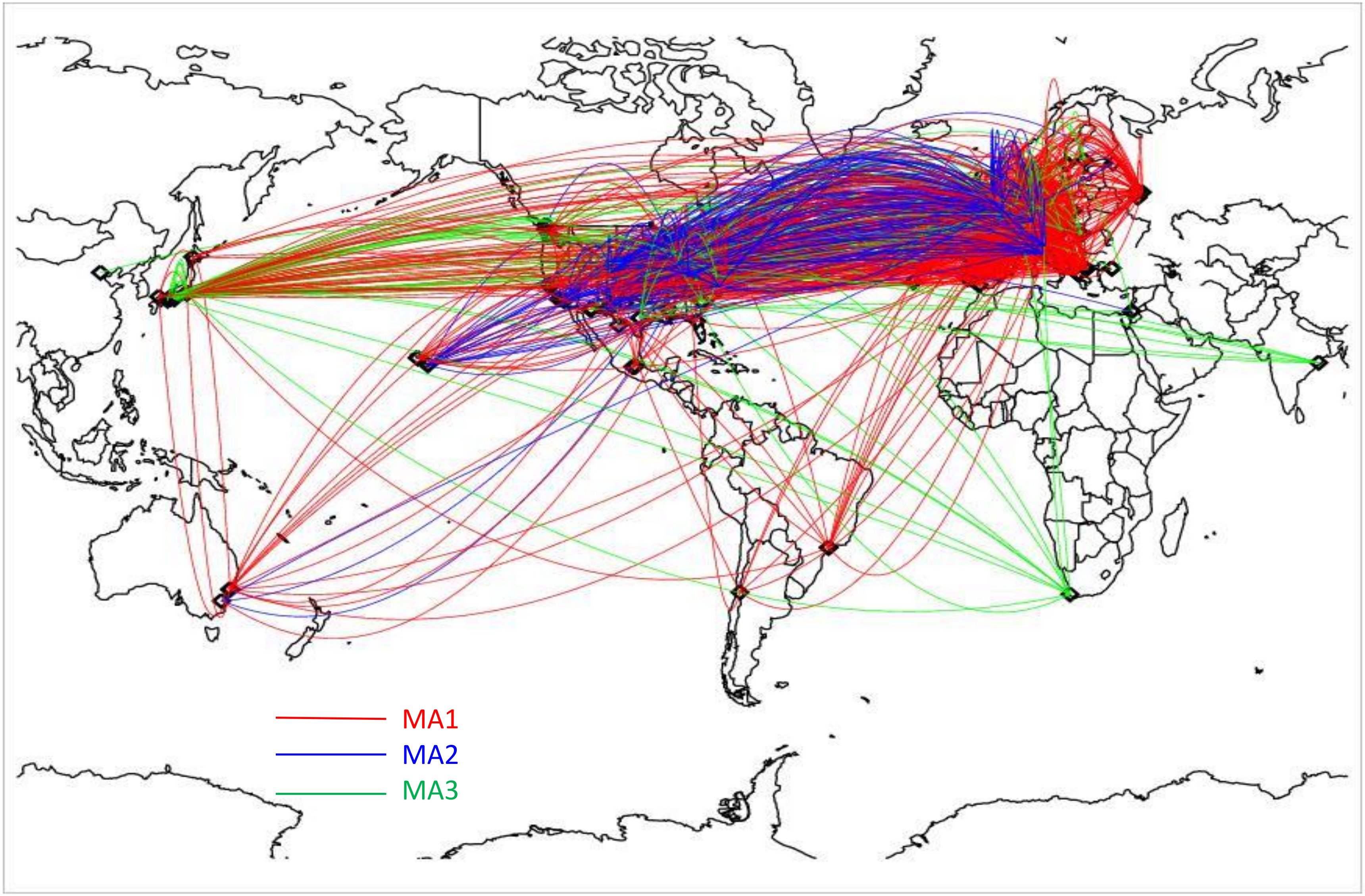
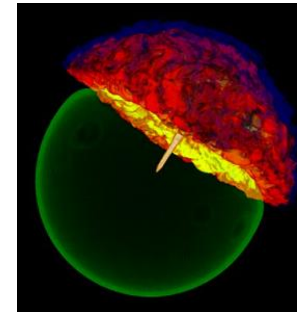
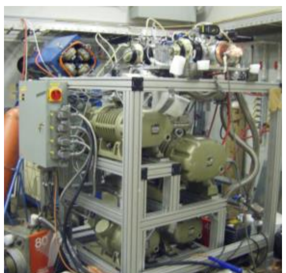
JINA



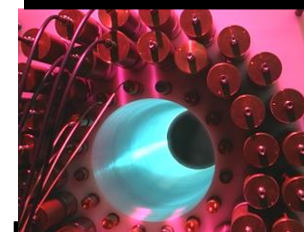
The JINA Mission



The Joint Institute of Nuclear Astrophysics:



- operates a **forefront research program** at the interface between experiment, theory, and observation
- provides **training and education** for young scientists
- motivates and initiates **new ideas & projects** in the field
- generates **new collaboration** and communication lines
- develops synergy & **common forum for the community**
- provides **service** to the scientific community
- operates an efficient and innovative **outreach** program



JINA Core Institutions

University of Notre Dame (**Director: Michael Wiescher**)

Experimenters, Modelers → Experimenters, Modelers, Observers

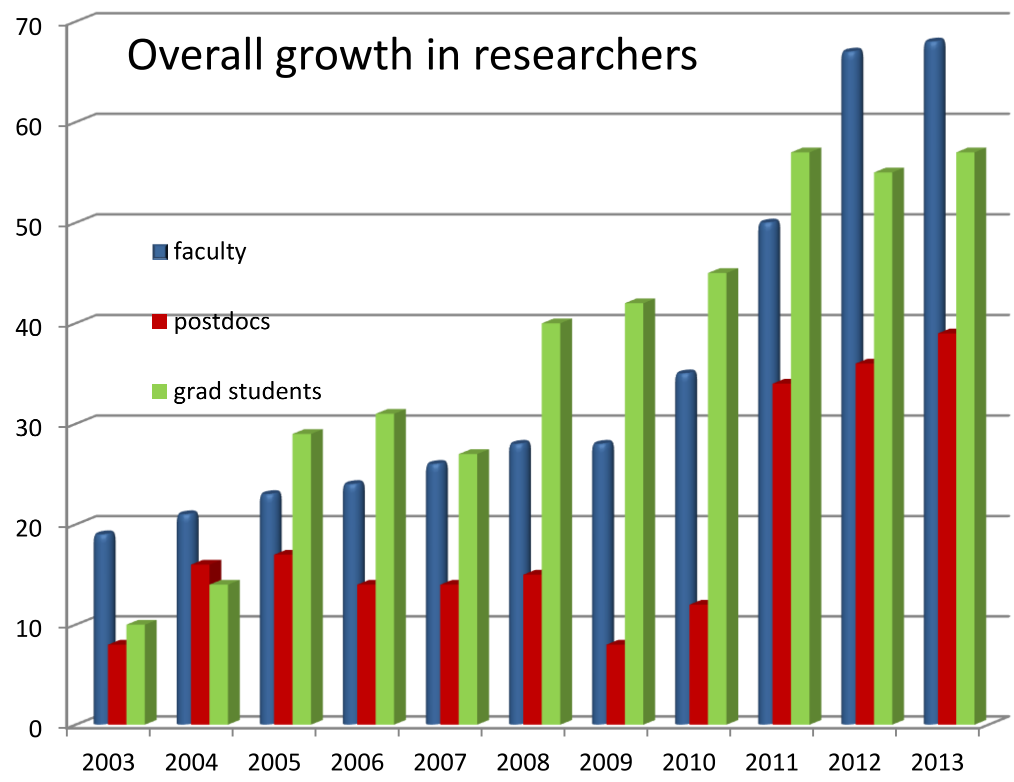
Michigan State University:

Experimenters, Observers → Experimenters, Modelers, Observers

University of Chicago:

Modelers → Modelers,

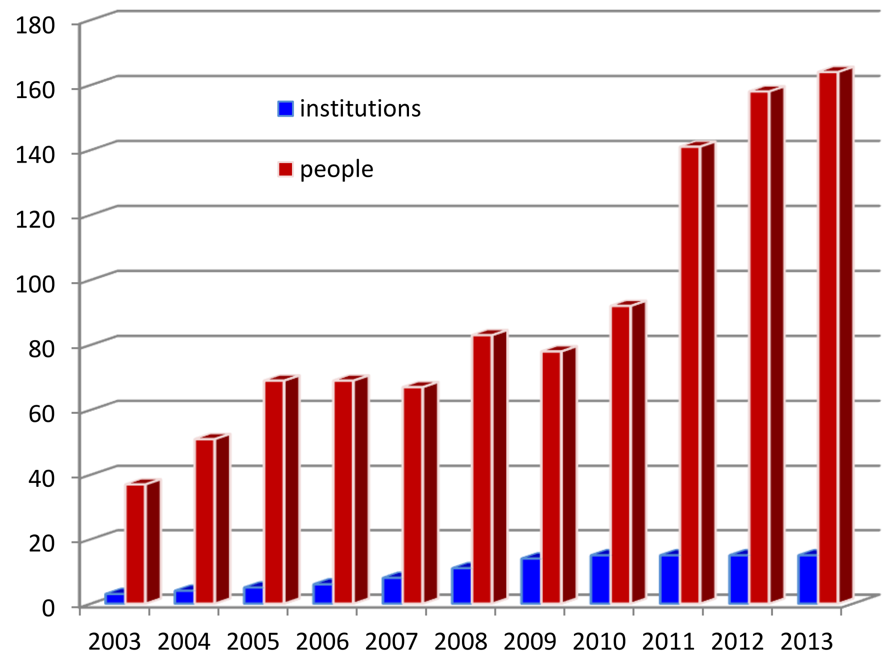
ANL Experimenters



JINA Associate Institutions

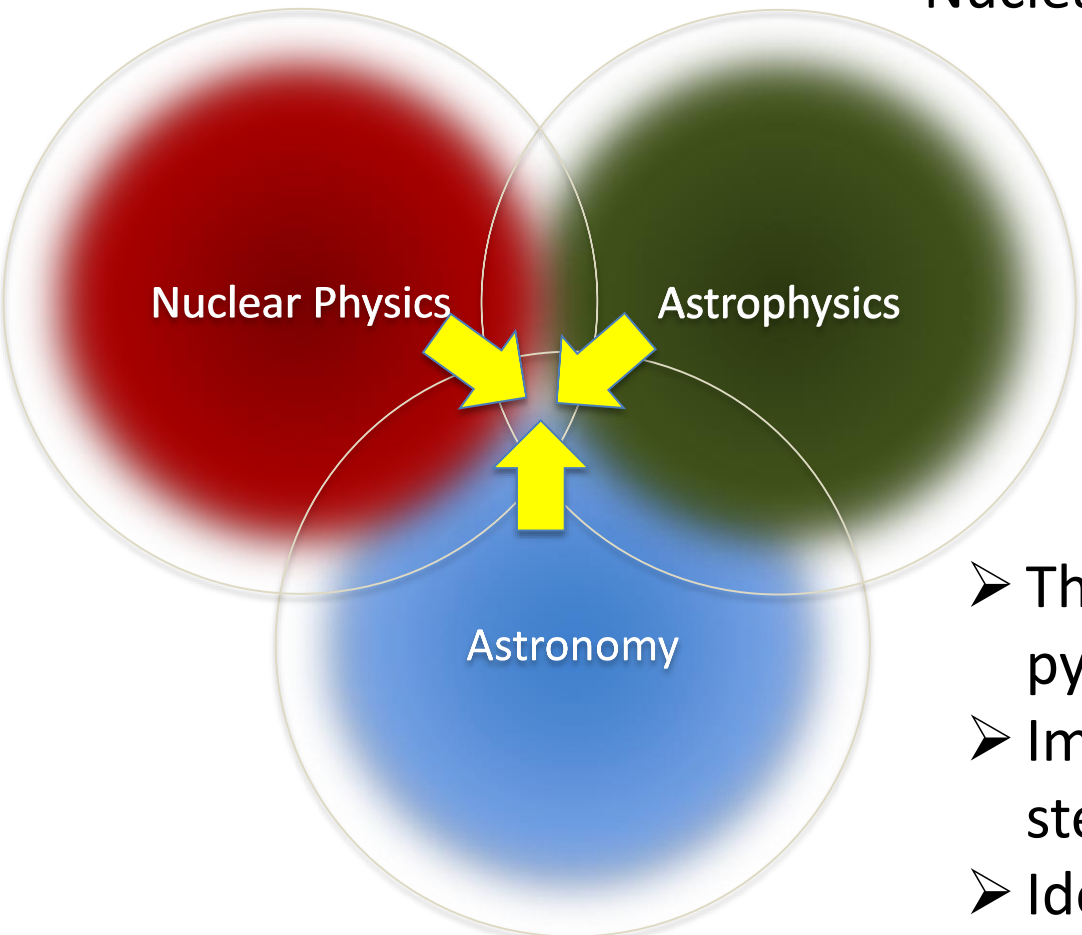
2003 Argonne National Laboratory
2004 Los Alamos National Laboratory
2004 UC Santa Barbara (until 2007)
2005 U. Arizona (until 2008)
2006 SDSS II and SDSS III
networking with 100 other institutions
2006 GSI Darmstadt, Germany
2006 Keele University, UK
2007 Arizona State University
2007 Lawrence Berkeley National Laboratory
2007 Western Michigan University
2008 EMMI Germany,
networking with 15 other institutions
2008 Princeton University
2008/2013 Monash University, Melbourne, Australia
2008 Ohio University
2008 University of Victoria, Canada
2009 University of Minnesota
2009 TU Munich, Germany
networking with 10 institutions
2011 Nuclear Astrophysics Virtual Institute NAVI
networking with 19 institutions
2012 Institute for Advanced Studies, University of Sao Paulo, Brazil
2013 New initiatives with China, CIAE Beijing, CNA Jiao Tong University Shanghai

Steady growth in external participants



NAVI is special

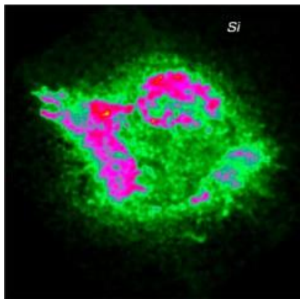
JINA Science



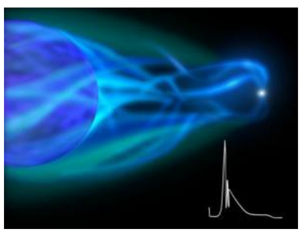
Nuclear Astrophysics transitioning from classical single group approach to collaborative community effort

- Thermonuclear and pycnonuclear processes
- Impact on stellar evolution and stellar explosion
- Identification and interpretation of new observables & signatures

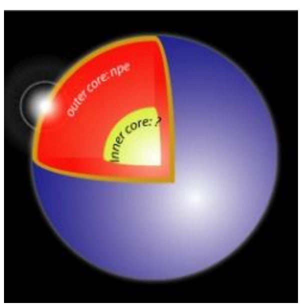
Major Activities in Nuclear Astrophysics



MA1: origin of the elements, the chemical evolution of our universe; stellar burning & evolution, type II SN, s-process, p-process, r-process



MA2: cataclysmic binary systems, from novae to type Ia supernovae; nova burning, mixing, type Ia SN ignition, fusion reactions, weak interaction



MA3: high density matter from the crust to the core of neutron stars; CNO break-out, rp-process, electron capture, degenerate neutron capture, pycnonuclear fusion, equation of state

Technical Project Developments

St.ANA & St.GEORGE for inverse kinematics studies
(NSL/ND; IUSB)

DIANA/CASPAR an accelerator facility underground
(NSL/ND; LBNL; UC Berkeley, UNC; CSM; SDSM&T, WMU; University of Naples, Italy; RU Bochum, Germany) ⇒ NSF

ReA3 astrophysics program and instrumentation
(NSCL/MSU; ....)

SECAR a recoil separator for ReA3 and FRIB
(NSCL/MSU; NSL/ND; ANL; ORNL; University of Louisiana) ⇒ DOE

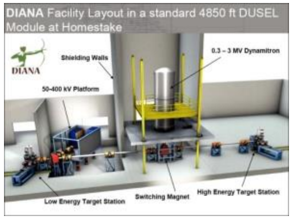
ELISE separator (FAIR/GSI), SHARAQ (RIKEN)
(NSL/ND, KVI, GSI, RIKEN) ⇒ completed

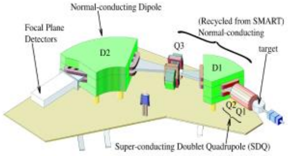
Dispersion Matching Super-FRS (GSI)
(NSL/ND, GSI)

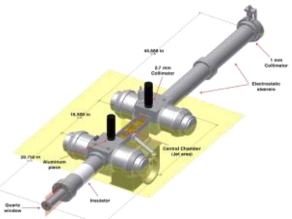
Gastarget (JENSA, DIANA) development
(ND/NSL, NSCL/MSU, CSM, LBNL, LSU, U. Naples, Italy, ORNL)

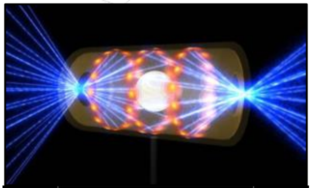
NIF as nuclear astrophysics probe
(ND/NSL, LBNL/LLNL, U. Ohio)

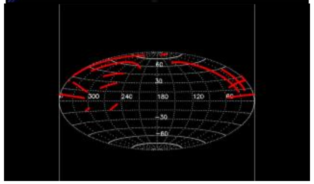
SDSS III SEGUE
(MSU, ND et al) ⇒ completed



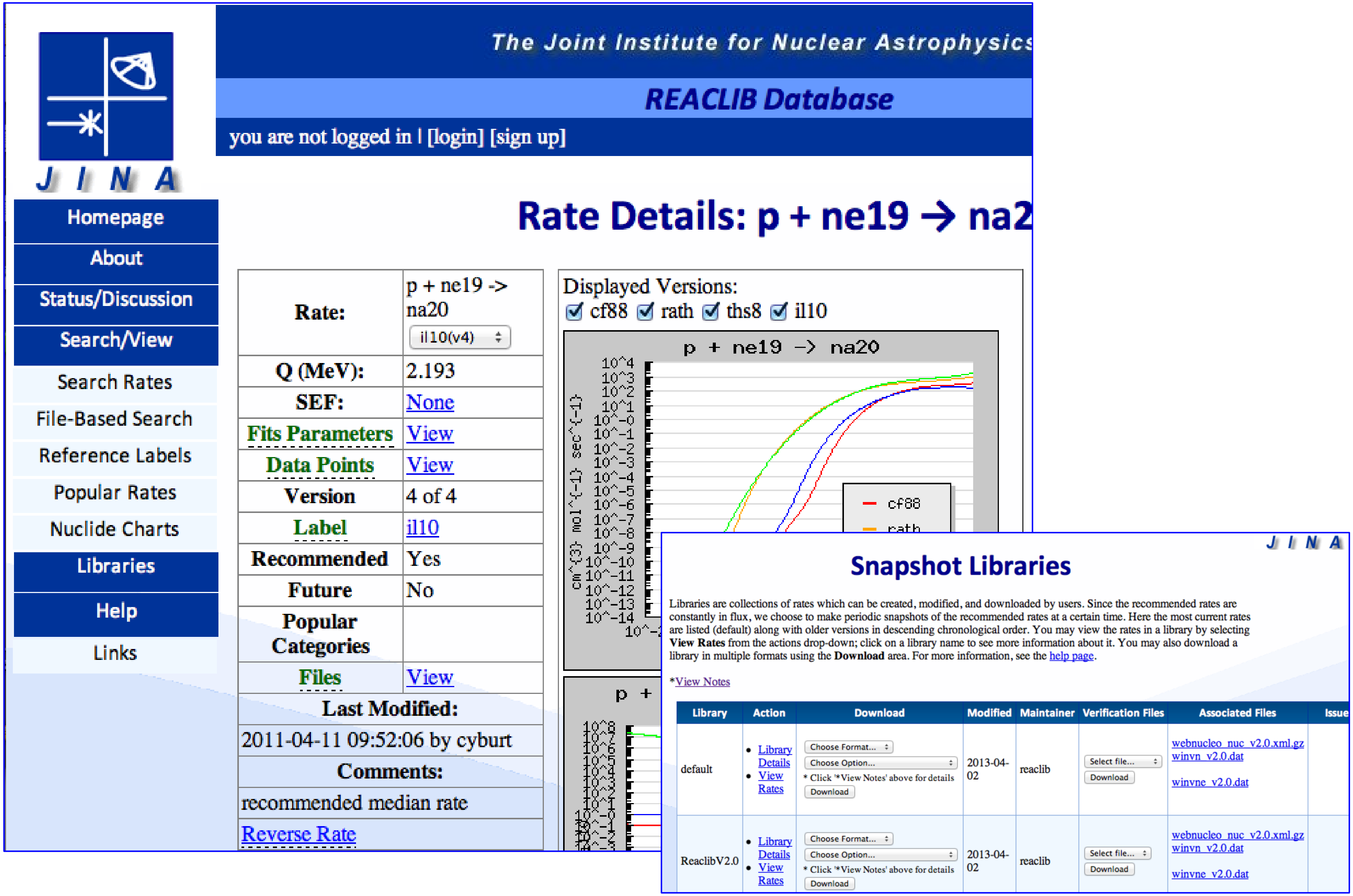








Reaclib Database: https://groups.nscl.msu.edu/jina/reaclib/db/



Virtual Journal: https://groups.nscl.msu.edu/jina/journals/jinavj/

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The Joint Institute for Nuclear Astrophysics

Virtual Journal of Nuclear Astrophysics

JINA - Virtual Journal of Nuclear Astrophysics, 29 November 2013

Volume 11, Issue 48 (30 Articles)

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 # 1 - Ages of young stars
David R. Soderblom, Lynne A. Hillenbrand, Rob D. Jeffries, Eric E. Mamajek, Tim Naylor
arXiv.org - Astrophysics - Volume: 2013, Issue: 2 Dec
arXiv:1311.7024 [pdf, other]

 # 2 - Cool carbon stars in the halo and in dwarf galaxies: Halpha, colours, and variabiity
Nicolas Mauron, Kamo S. Gigoyan, Paul Ber
arXiv.org - Astrophysics - Volume: 2013, Iss
arXiv:1311.6977 [pdf, ps, other]

 # 3 - Europium production: neutron
F. Matteucci, D. Romano, A. Arcones, O. Ko
arXiv.org - Astrophysics - Volume: 2013, Iss
arXiv:1311.6980 [pdf, ps, other]

Weekly compilation
all nuclear astrophysics articles
From 41 Journals

J I N A school program provides:

Motivation, Involvement, Training

Communication & Community Building

Often: Hands on, focused

In collaboration with partners

Check JINA website for new schools: TALENT course May/June 2013

JINA outreach programs

Total audience approaching ~10,000 per year

From ART to SCIENCE (with special summer camp)
Special needs programs and after-school programs for at-risk children are invited to join us in igniting stellar imaginations.

Physics of the Atomic Nuclei (PAN) Program @ MSU
A two week program offering lectures, demonstrations, hands-on experiments @ MSU.

PIXE-PAN Summer Science Program @ Notre Dame
A two week program offering lectures, demonstrations, hands-on experiments @ NSL at ND.

Research Experience Program for High School Students
High school students work in the Nuclear Structure Laboratory for one or more semesters earning college course.

Bringing Science into the Classroom: JINA Classroom Mini-Grants
JINA's Classroom Materials Mini-Grant Program is intended to provide the means to enhance science curricula with classroom materials that might not otherwise be utilize

Field Trip and Travel Support
Support for K-12 classes to tour the NSCL at Michigan State or the NSL at Notre Dame.

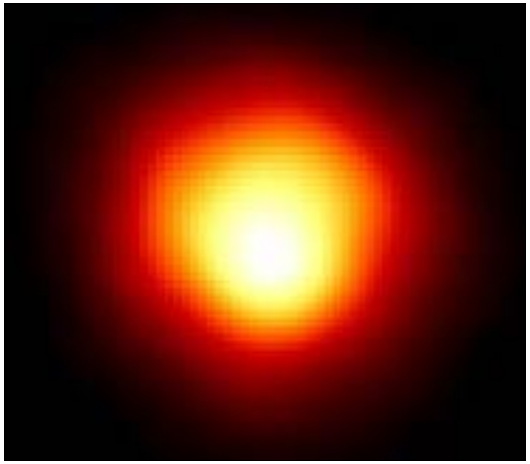
Catch a Cosmic Ray at NSCL
Dvelve into the problem of cosmic rays with a hands-on experiment.

Mathematics, Science, and Technology (MST)
Run by MSU's Honors College, this residential camp offers intensive two-week courses to over 100 high-achieving middle school students each summer.

From K-12 + teachers

Includes assessment, collaboration with education experts

Art to Science Observations (Michael Wiescher)

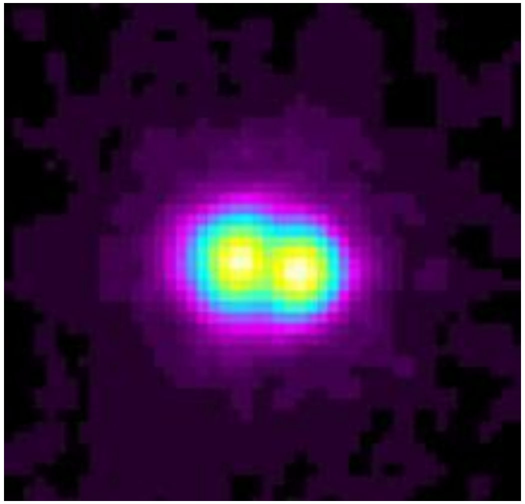


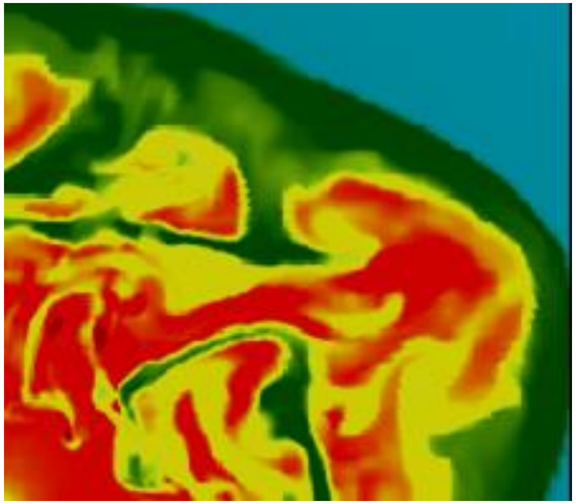
Close correlation from the director's point of view

Stars

Cataclysmic Binaries

Supernovae



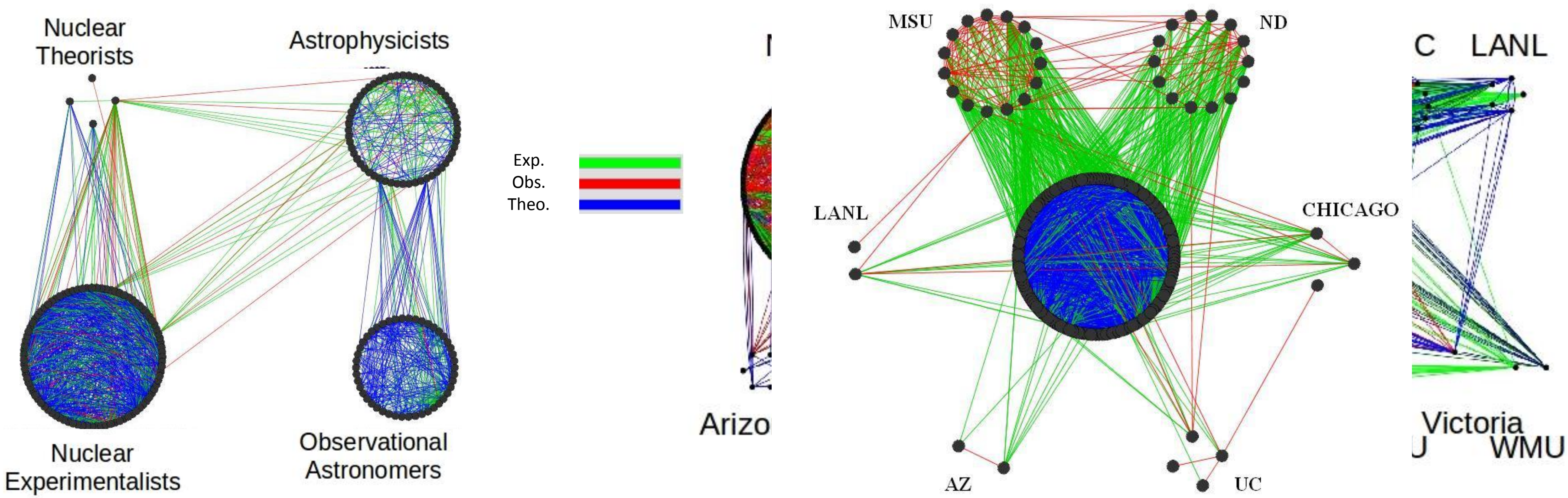


Community Building

By generating a communication & collaboration network
JINA succeeded to establish itself as global Physics Frontier Center!

- JINA has motivated and demonstrated interdisciplinary community efforts
- JINA has generated communication & interaction patterns
- JINA has helped in the dynamics of merging communities
- JINA maintains a forefront and competitive science program

JINA provides the network between different previously non-interacting communities with common goals but different tools and techniques!



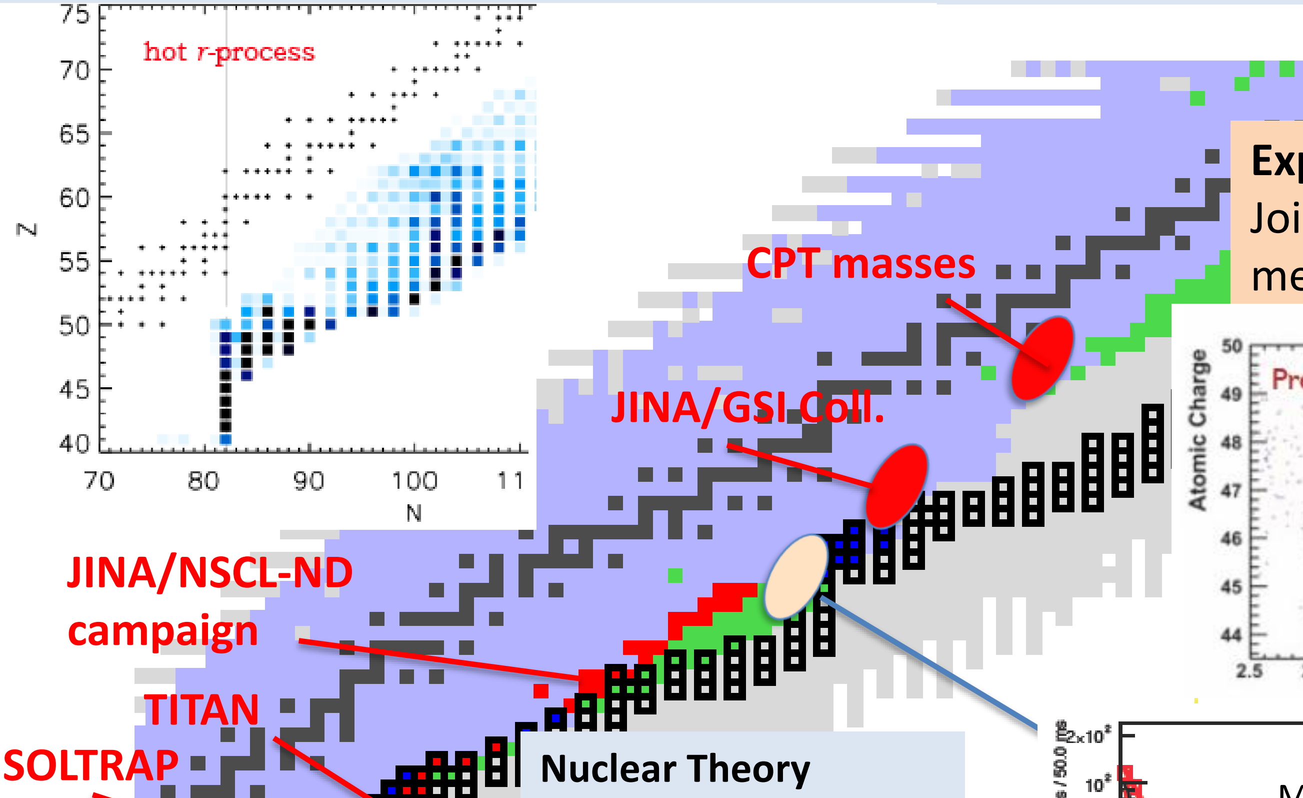
JINA Science: MA1

MA1: Galactic Chemical Evolution

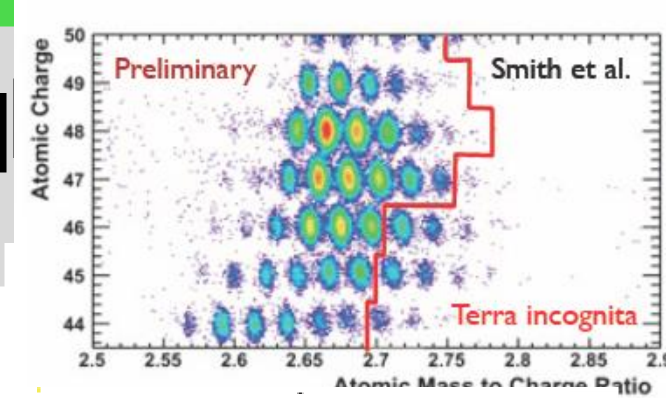
- What is the origin of the elements?
- What do element observations tell us about stars, supernovae and galaxies?
- What is the C, N, O content of the sun?

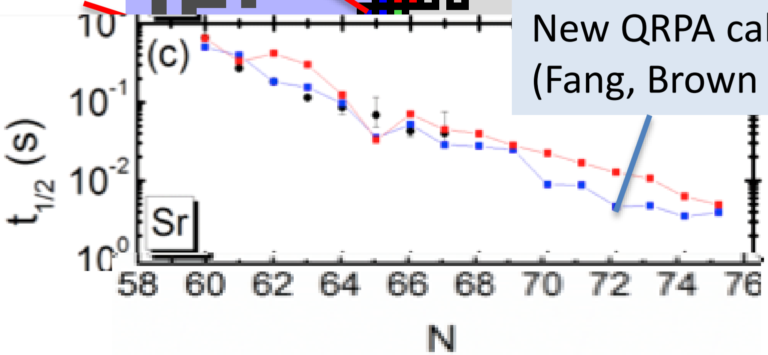
r-process studies

Astro modeling: New sensitivity studies T12 and masses (Mumpower, Cass, Passucci, Surman, Aprahamian)

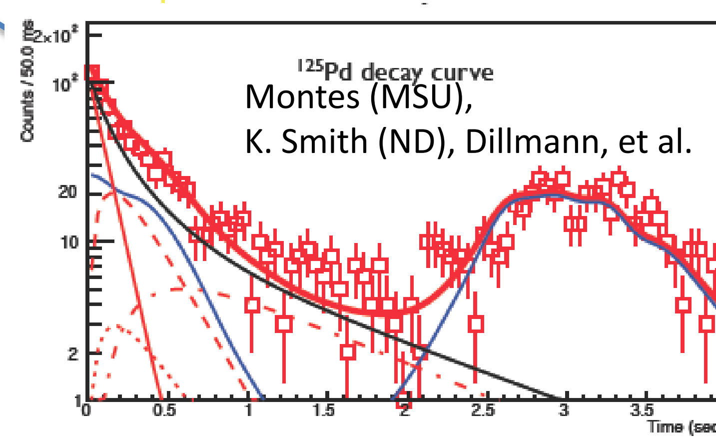


Experiment:
Joint JINA (MSU, ND) – EMMI measurement @ GSI





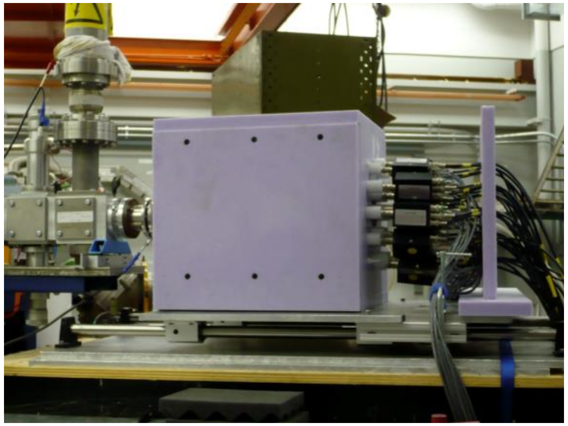
Nuclear Theory
New QRPA calculations (Fang, Brown 2013)



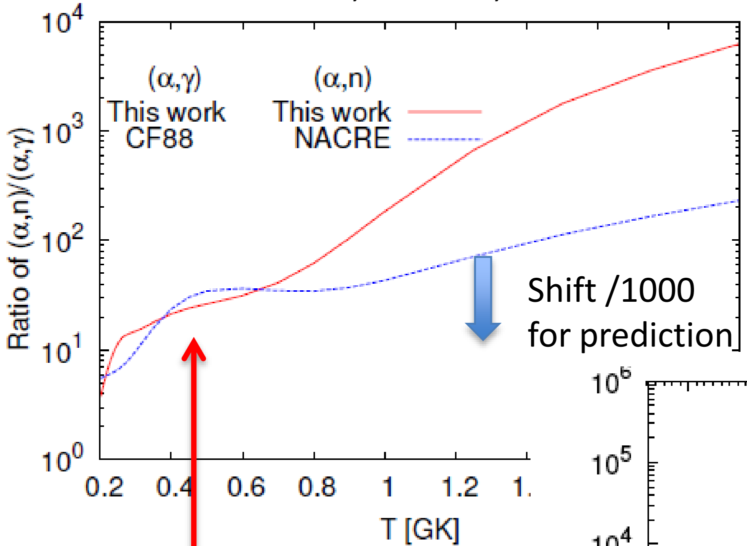
Montes (MSU), K. Smith (ND), Dillmann, et al.

S-process neutron source experiments at Notre Dame

Notre Dame experiments



Best, deBoer, et al.



Measured at ND $^{17}O(\alpha,g)$ and $^{17}O(\alpha,n)$ plus **R-matrix analysis** → Ruled out Predicted $^{17}O(\alpha,g)/1000$

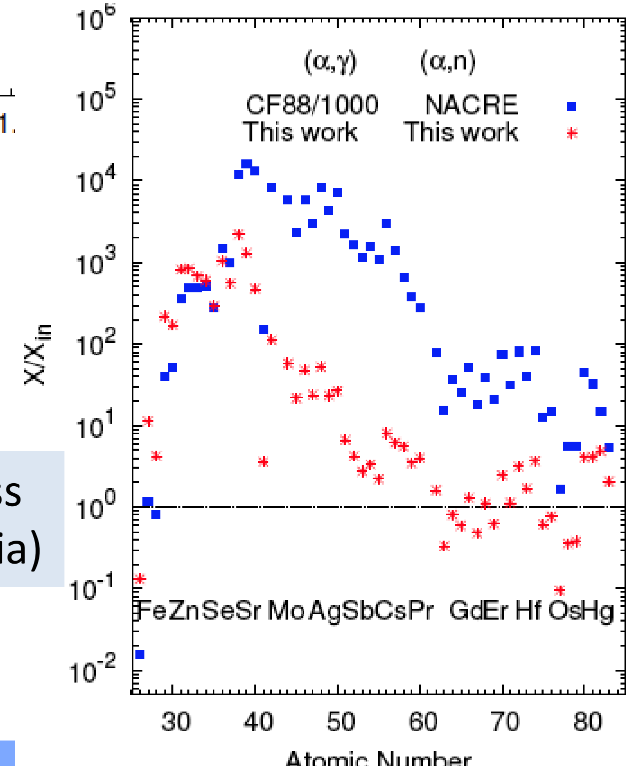
New results on $^{17}O(\alpha,n)^{20}Ne$
$^{18}O(\alpha,n)^{21}Ne$, $^{22}Ne(\alpha,n)^{25}Mg$,
$^{25}Mg(\alpha,n)^{28}Si$, $^{26}Mg(\alpha,n)^{29}Si$
$^{12}C(^{12}C,n)$

+ $^{22}Ne(\alpha,n)^{25}Mg$ γ-beams at HIGS

Comparable ratio but each rate ~1/4

Consequences:
→ weak s-process production A~90
→ Seed for p-process

Weak s-process models (Victoria)

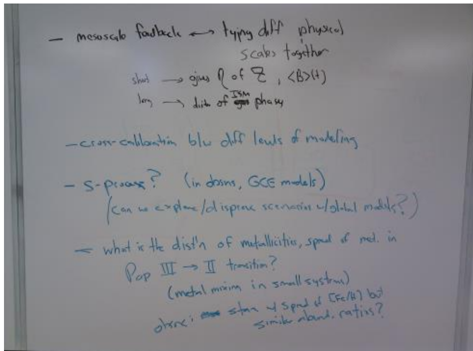


Bringing it all together: advanced GCE modeling

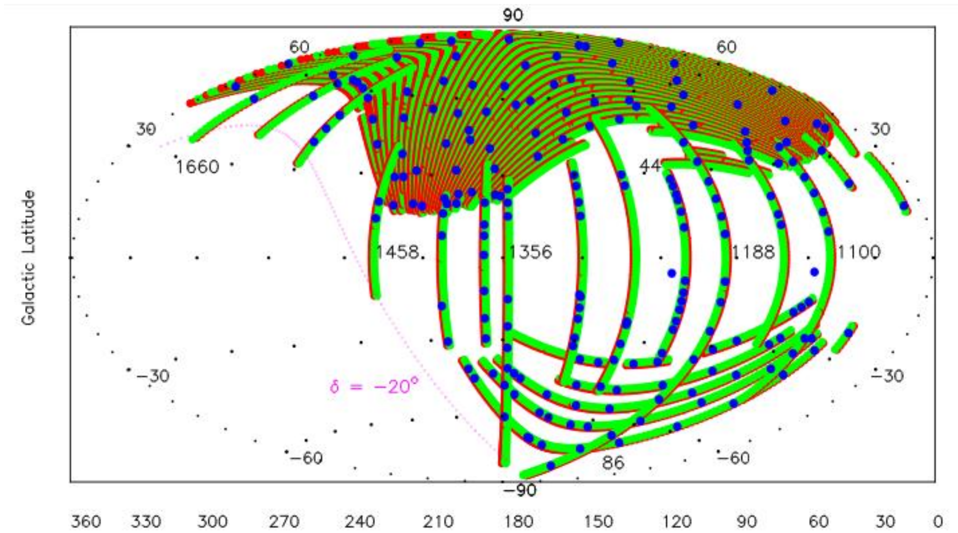
Input: Goal: NuGRID stellar yields incl s-process, r-process, SNIa, … plus energies.

Virtual Galaxy Workshop

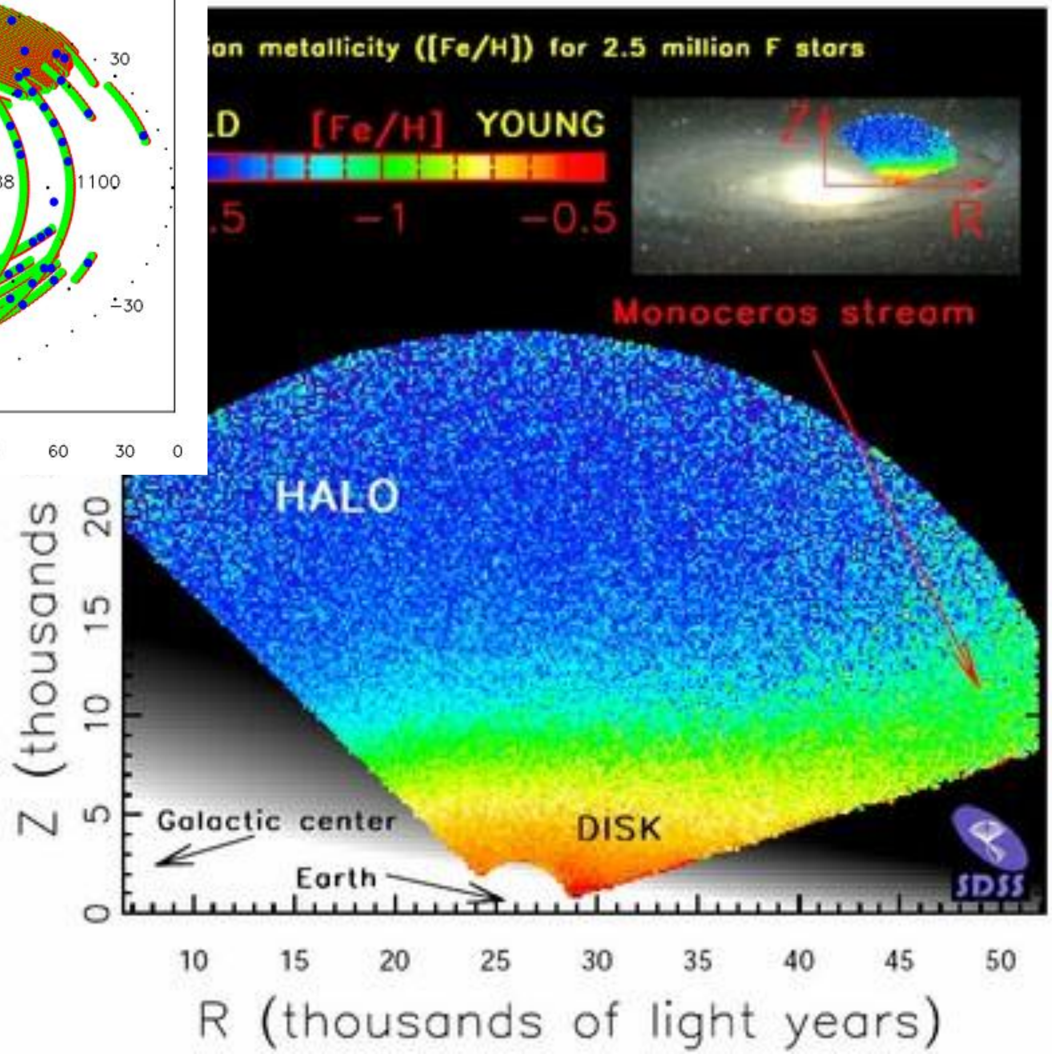
(MSU, April 2010, O’Shea/Beers)

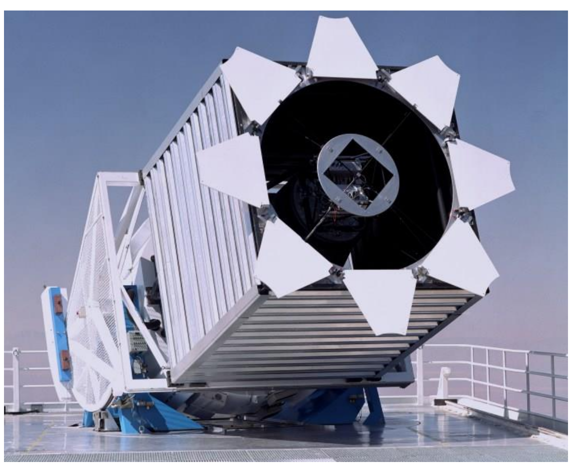


SDSS-SEGUE Observations



260,000 stars. 60,000 G-dwarfs

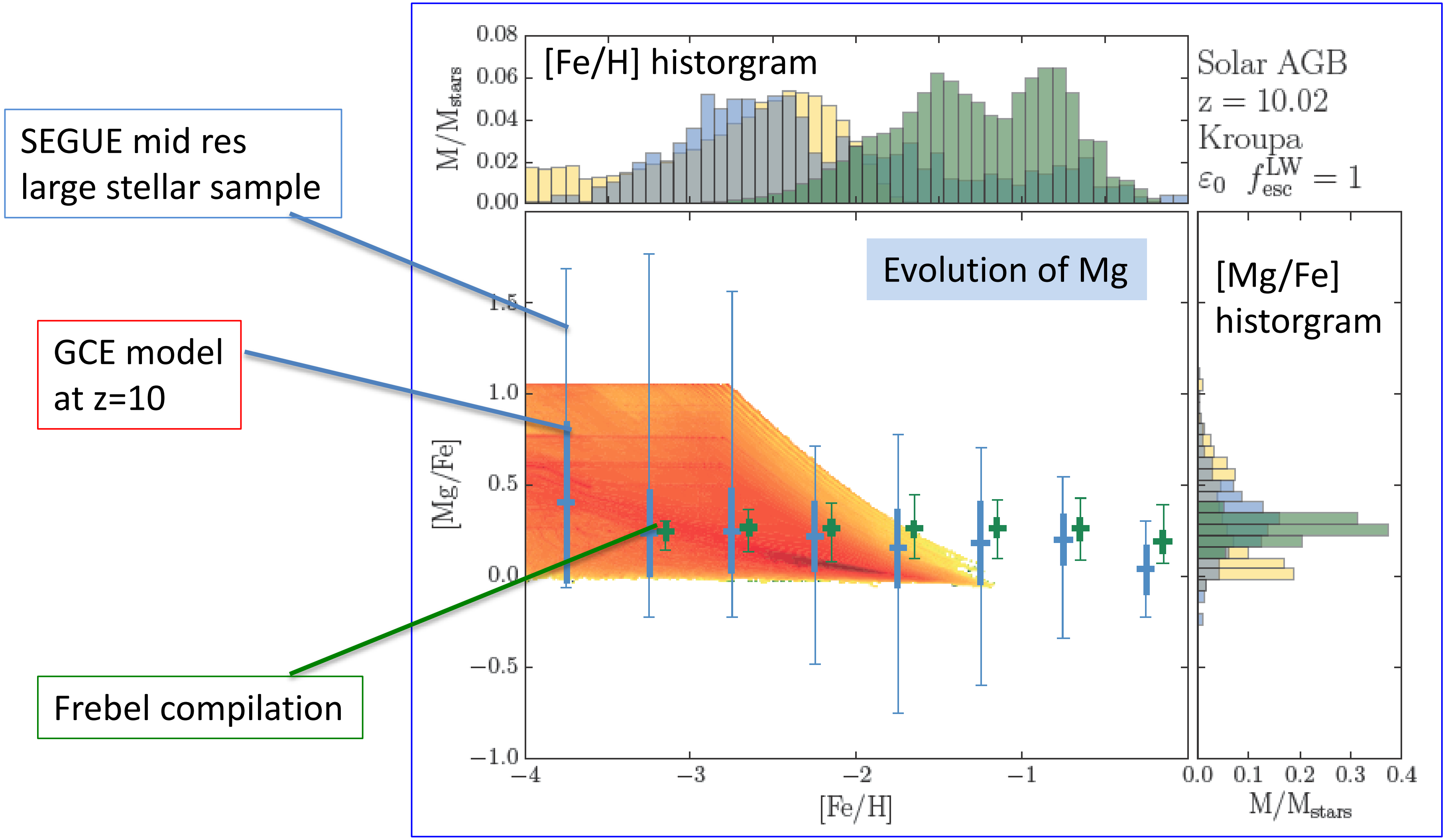




Galactic Chemical Evolution

New GCE model: Halo merger tree + semi-analytical star formation: Crosby et al. 2013

Currently track: C, N, O, Mg, Ca, Ti, Fe, Co, Zn, Eu, Ba, Sr for stars and gas

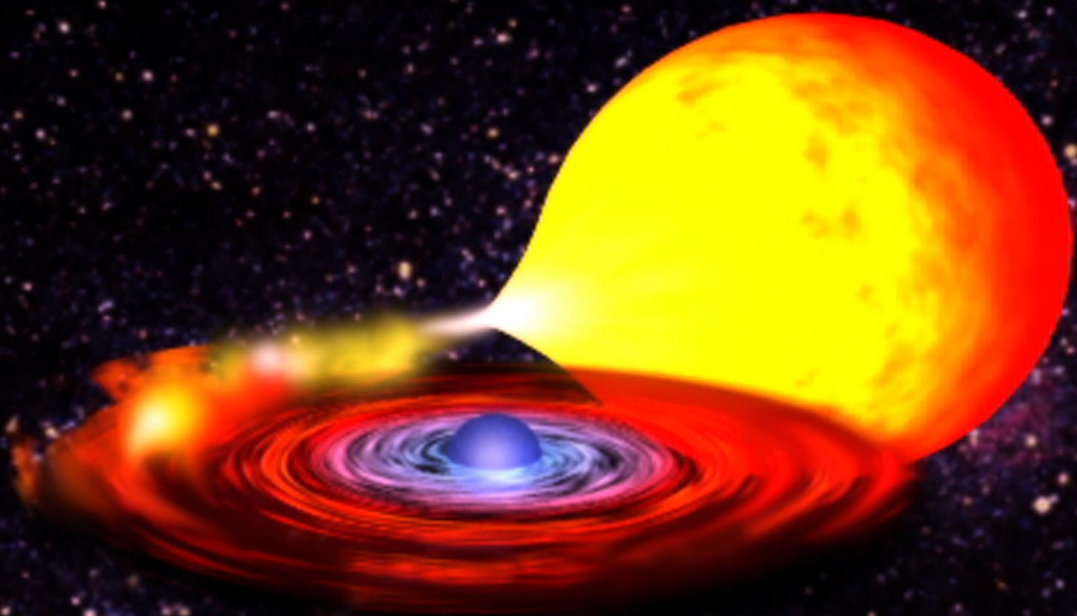


JINA Science MA3

MA3: Accreting neutron stars

- Why do X-ray burst models fail to describe many X-ray burst properties?
- What can bursts and cooling transients tell us about neutron stars?
- What are constraints on neutron star properties from nuclear experiments?

Accreting neutron stars



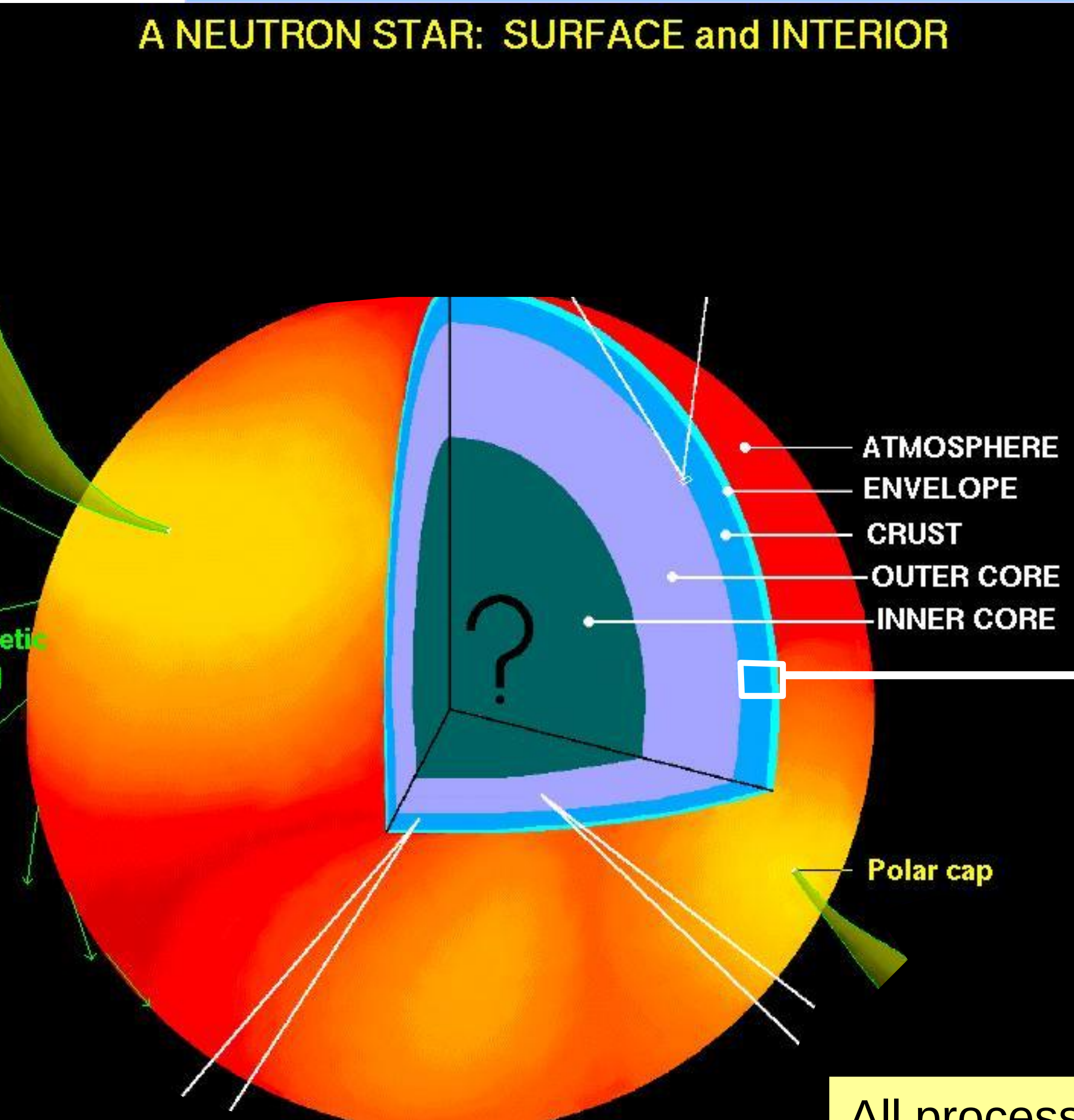
Many new observations with Chandra, XMM, RXTE

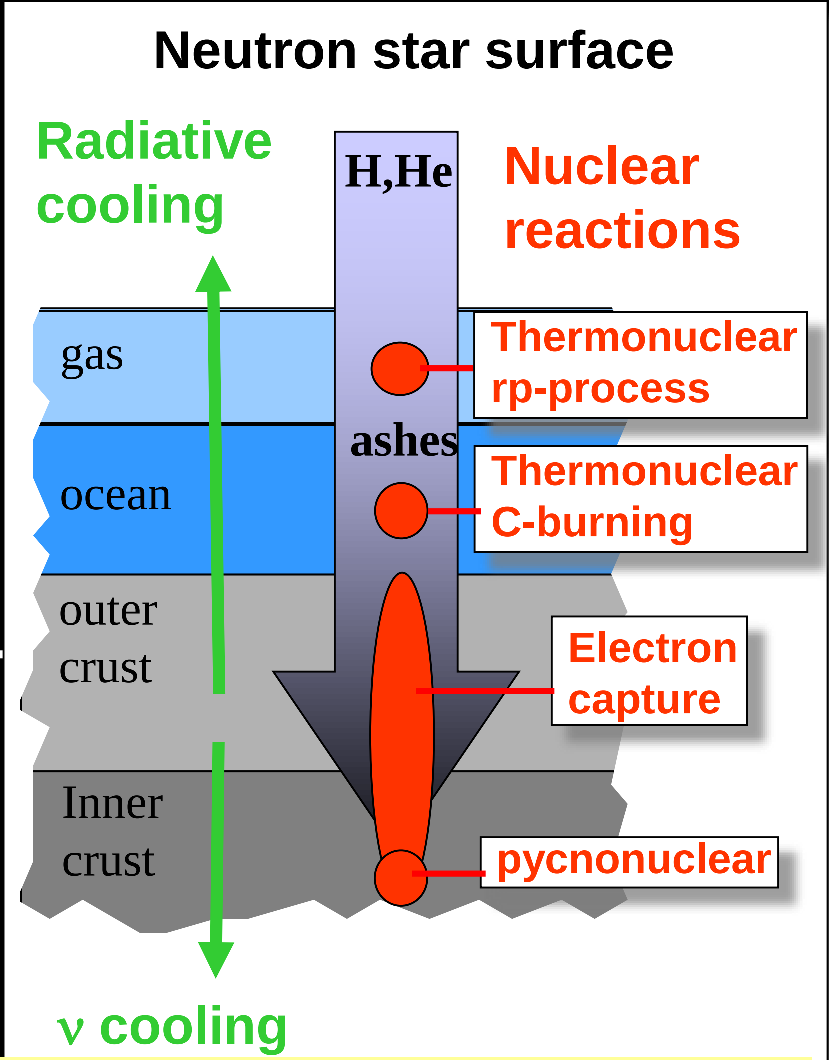
→ New, interesting phenomena (superbursts, …)

→ Constrain neutron star properties

(they get heavier, hotter, and spin faster than isolated NS)

Surface of accreting neutron stars

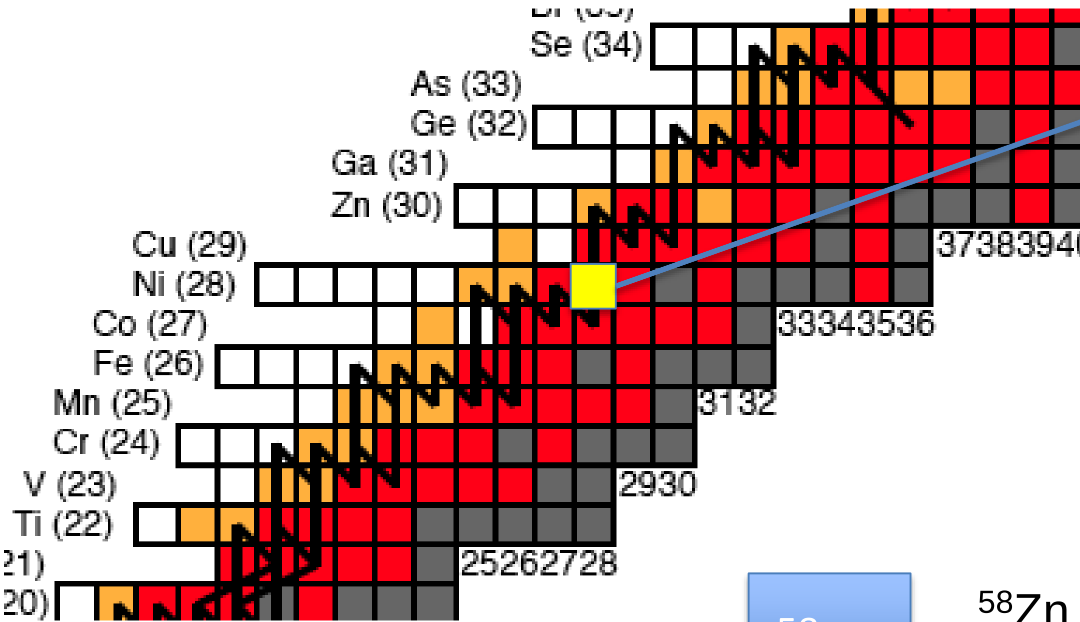




). Page

All processes are connected:
- composition (ashes = seed for next process)
- heat release → thermal conditions everywhere

The ^{56}Ni "waiting point"

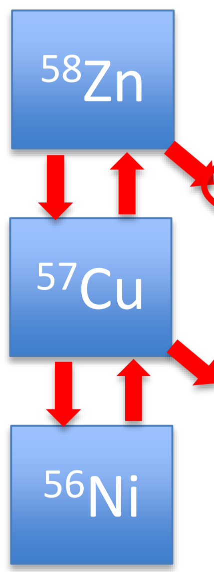


^{56}Ni – a special Bottle neck ('stable' on burst timescale half-life ~4 hours)

T < 0.7 GK

0.7 GK < T < 1.5

T > 1.5 GK



^{58}Zn mass

^{57}Cu β-decay $T_{1/2}$

^{57}Cu(p,γ) rate **The missing piece**

^{57}Cu mass,

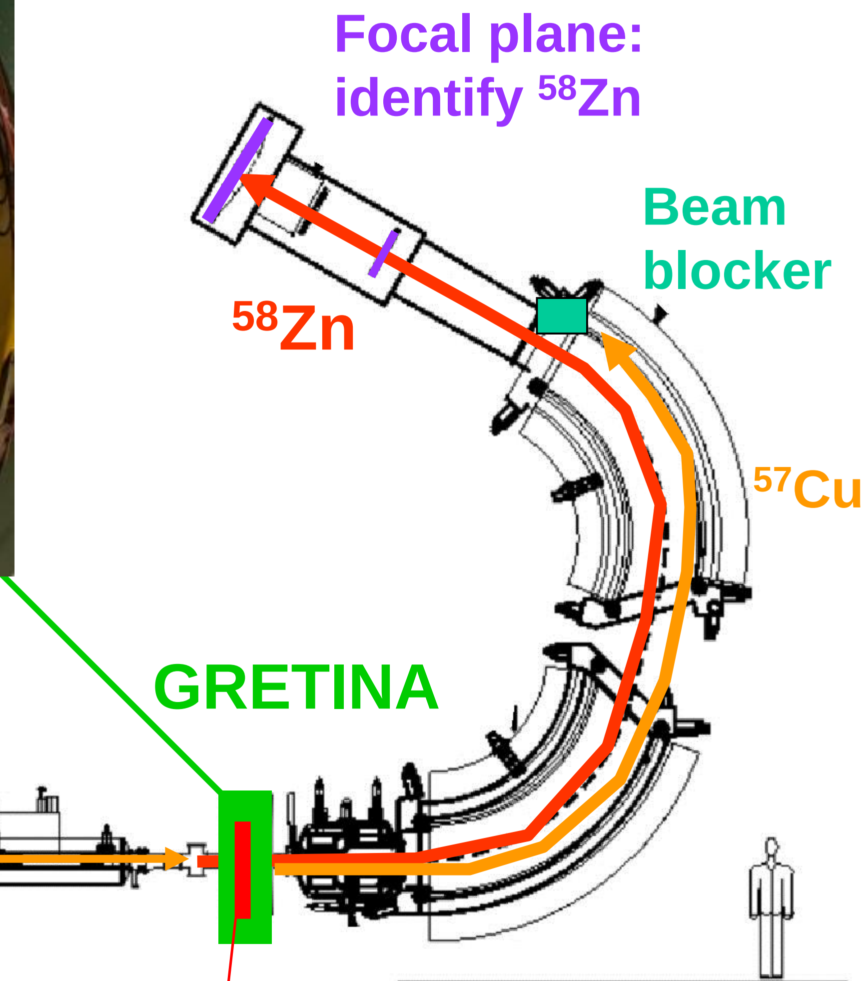
^{57}Cu β-decay $T_{1/2}$

^{56}Ni(p,γ) rate Rehm et al. 1998

^{56}Ni mass

First GRETINA Experiments at NSCL

Christoph Langer
Fernando Montes

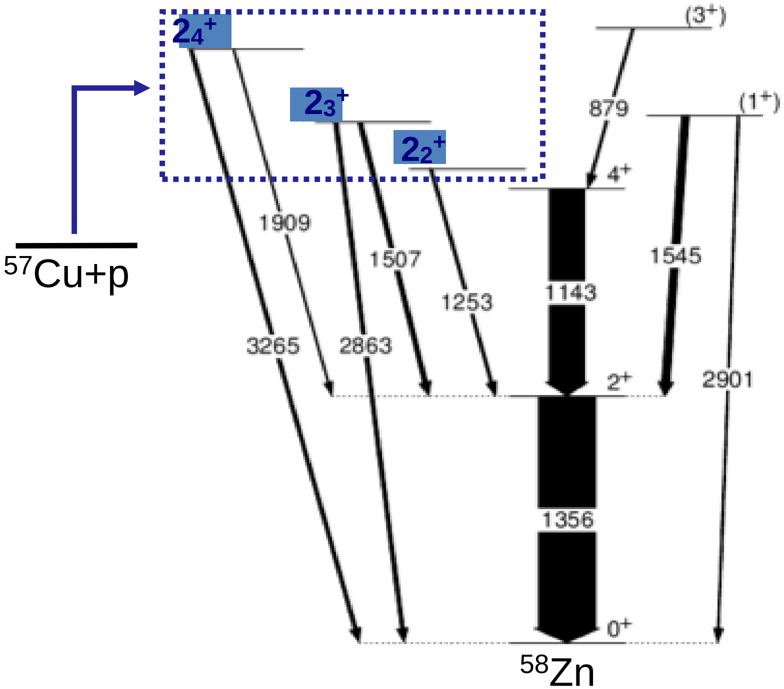


Radioactive ^{57}Cu beam
3×10^4 pps
75 MeV/u

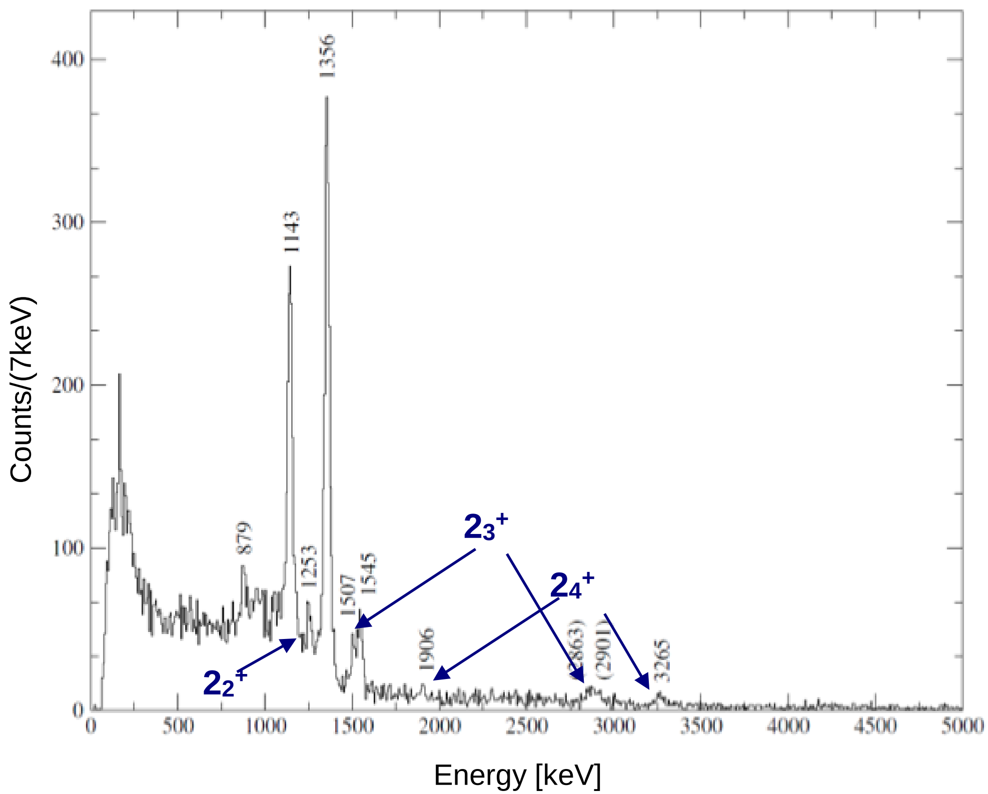
Deuterated plastic target (225 mg/cm^2)
^{57}Cu + d → ^{58}Zn + n

Indirect Reaction Rates with GRETINA

Deduced levels

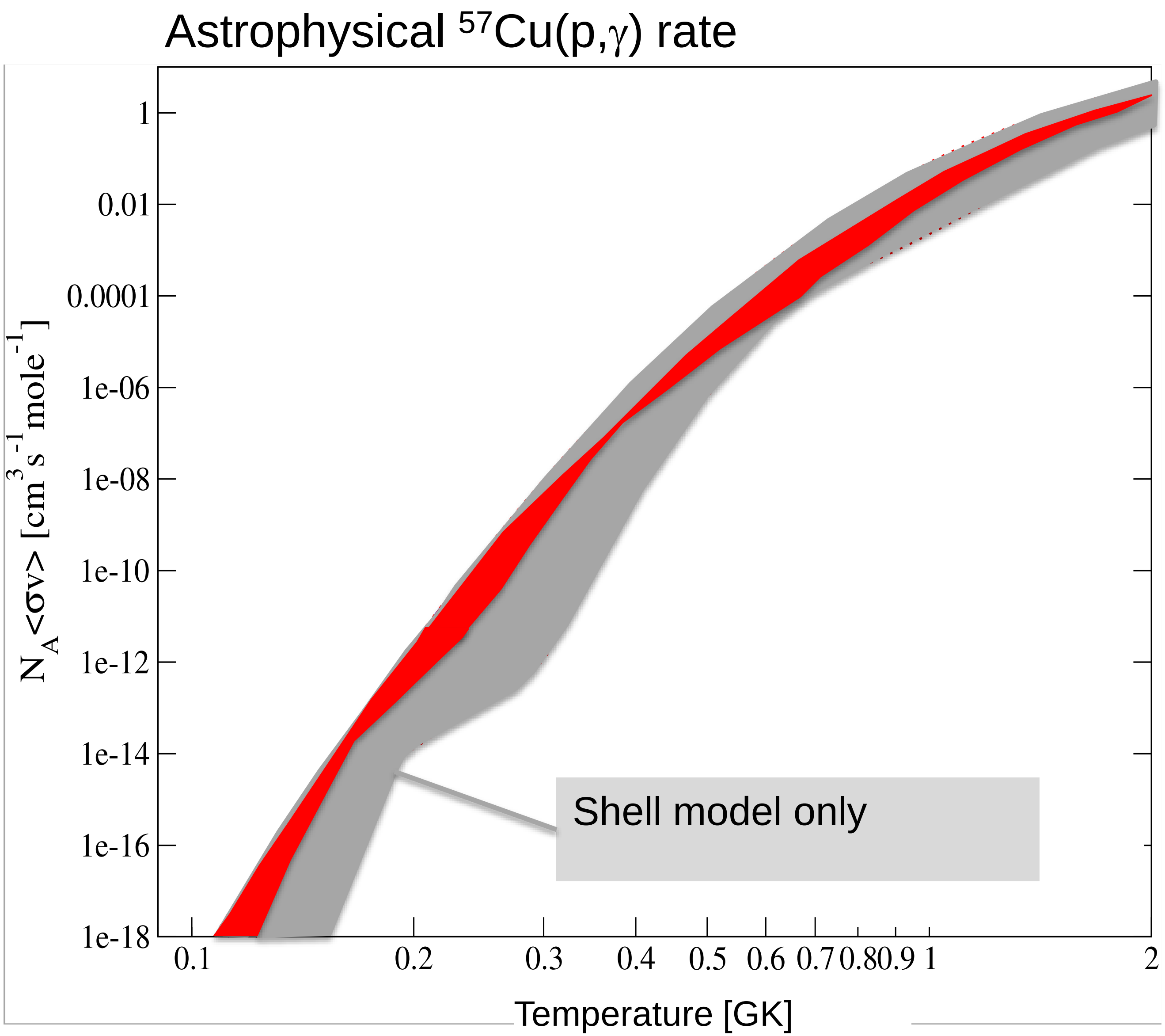


Measured γ-ray spectrum

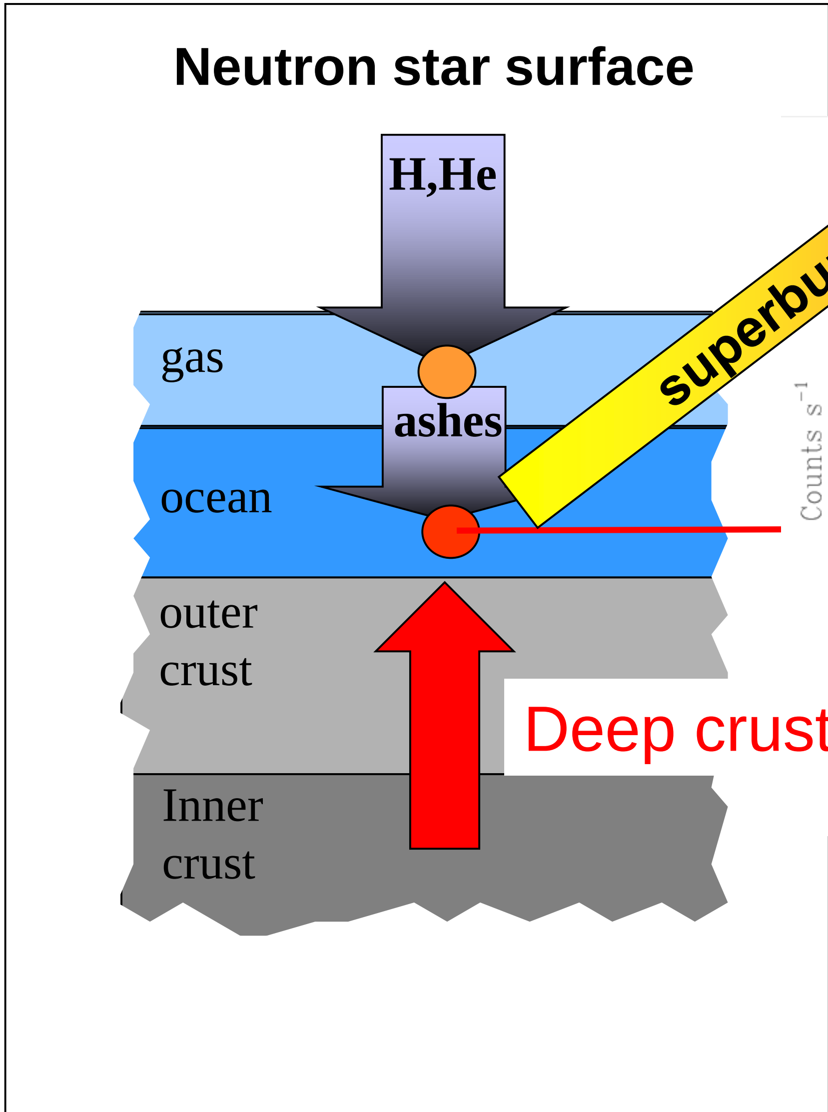


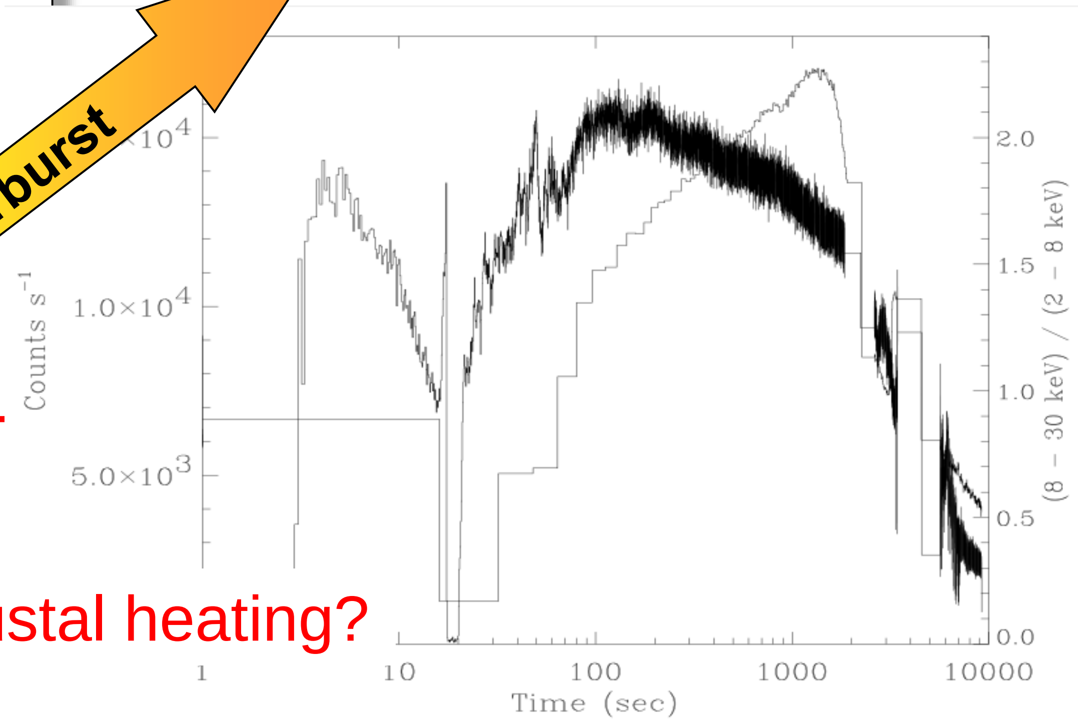
Langer, Montes, et al. 2013 (in prep)

Astrophysical Reaction Rate



Step 2: Deep ocean burning: Superbursts





~22 bursts from 13 sources

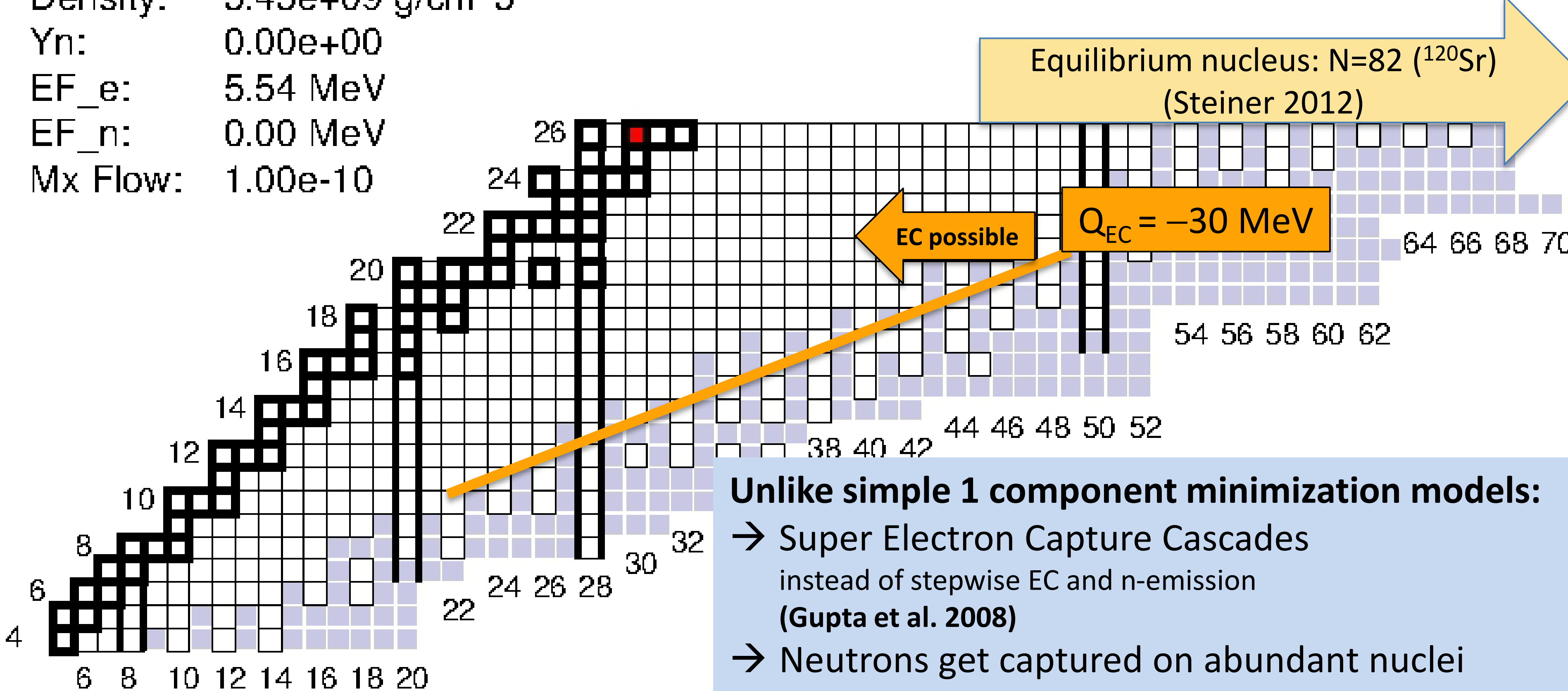
recurrence time 1-2 years

model prediction: 10 years?

Crust processes: Electron capture and neutron emission

Masses: FRDM
Electron capture/β-decay: QRPA (P. Moeller, S. Gupta)
Neutron capture: TALYS,
degeneracy and plasma corrections (Shternin et al. 2012)

Time:	4.525e+08 s
Temp:	0.50 GK
Density:	3.43e+09 g/cm^3
Yn:	0.00e+00
EF_e:	5.54 MeV
EF_n:	0.00 MeV
Mx Flow:	1.00e-10



Unlike simple 1 component minimization models:

→ Super Electron Capture Cascades
instead of stepwise EC and n-emission
(Gupta et al. 2008)

→ Neutrons get captured on abundant nuclei
path splits, multi isotope composition

→ No path to equilibrium (Jones 2005)

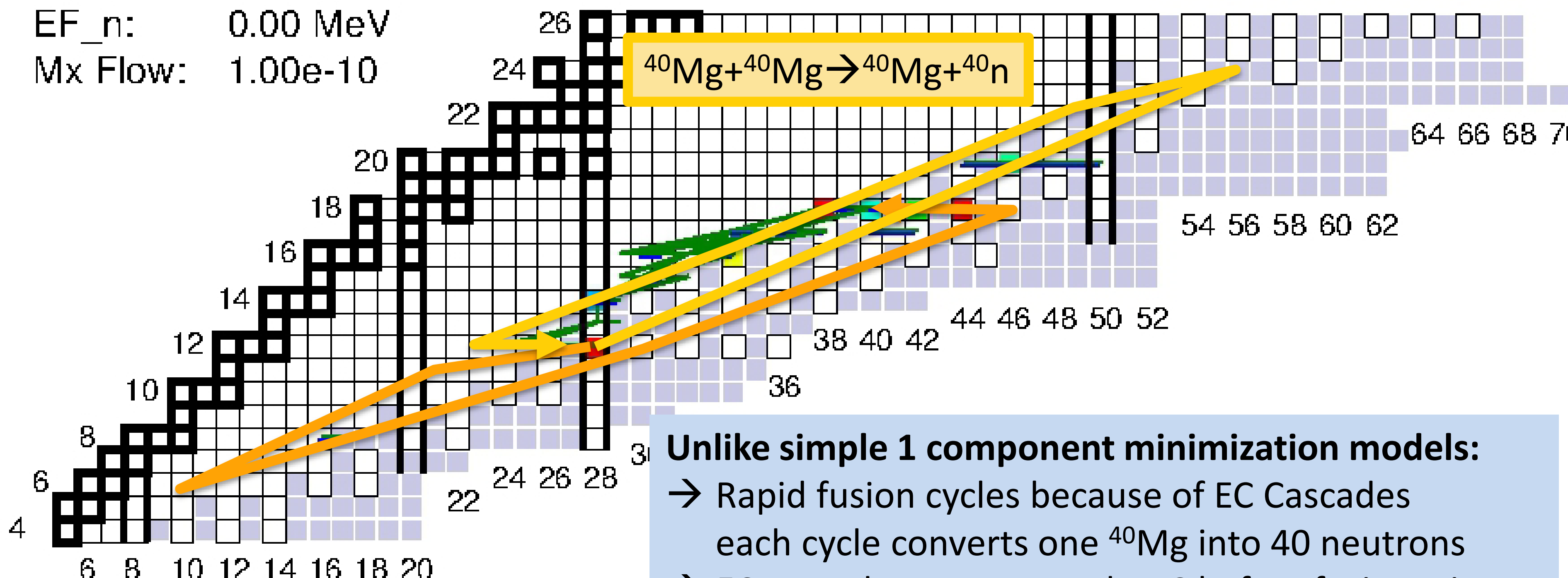
EC, (n,γ)

β-decay, (γ,n), fusion

Crust processes: Pycnonuclear fusion cycles

Pycnonuclear fusion rates: M. Beard, D. Yakovlev, et al. 2010

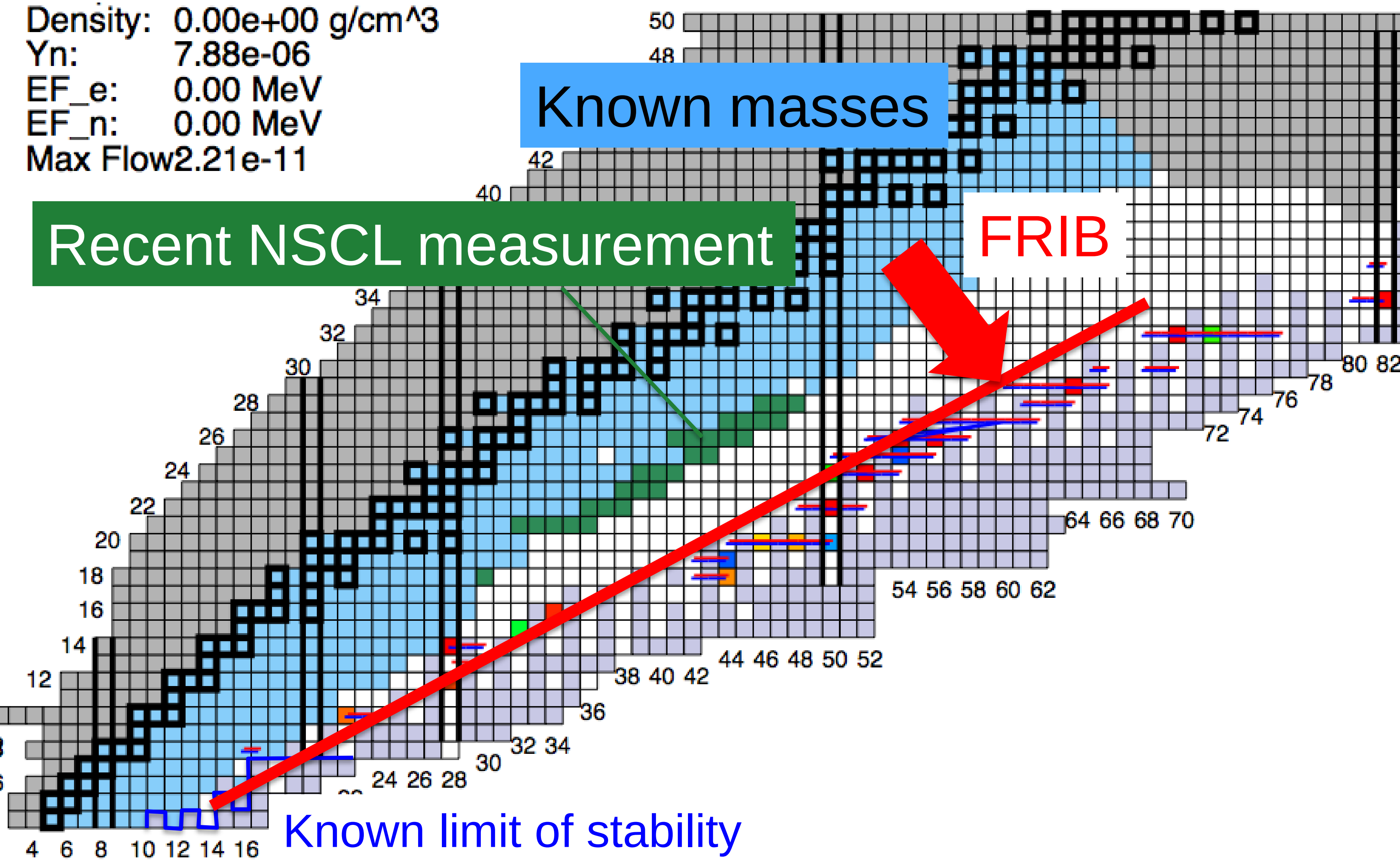
Time: 3.186e+11 s
Temp: 0.50 GK
Density: 7.34e+11 g/cm^3
Yn: 1.08e-07
EF_e: 30.42 MeV
EF_n: 0.00 MeV
Mx Flow: 1.00e-10



Unlike simple 1 component minimization models:

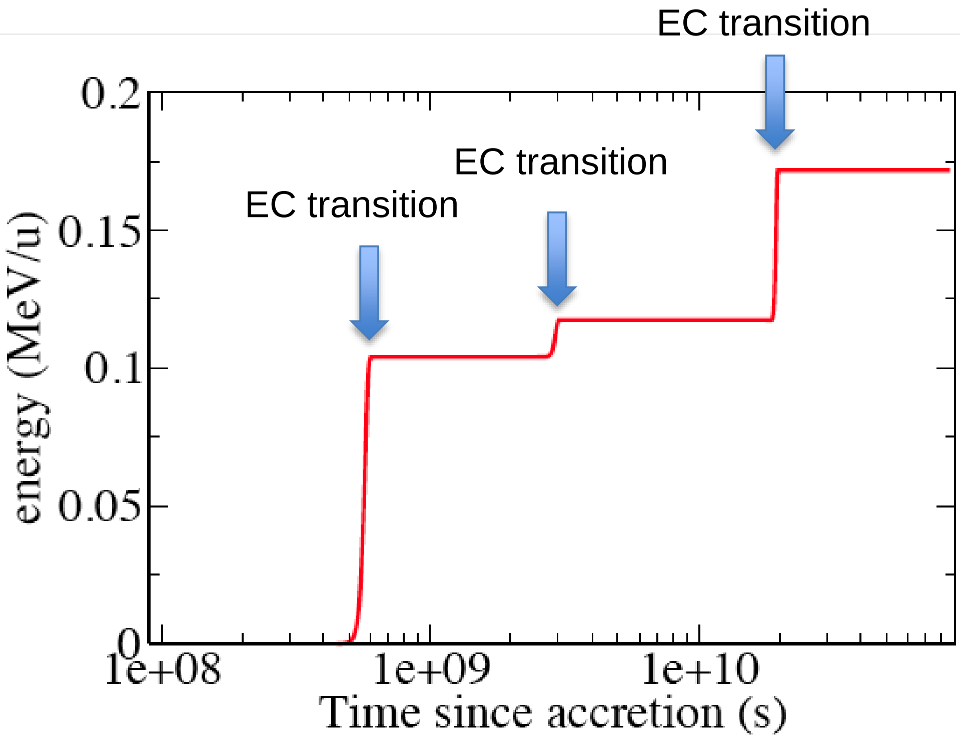
→ Rapid fusion cycles because of EC Cascades
each cycle converts one ^{40}Mg into 40 neutrons
→ EC cascades can proceed to C before fusion wins
→ Multiple ion composition → many fusion reactions
$^{40}Mg+^{25}N$, $^{40}Mg+^{40}Mg$, $^{40}Mg+^{28}O$, $^{40}Mg+^{20}C$, …

EC, (n,γ)
β-decay, (γ,n), fusion

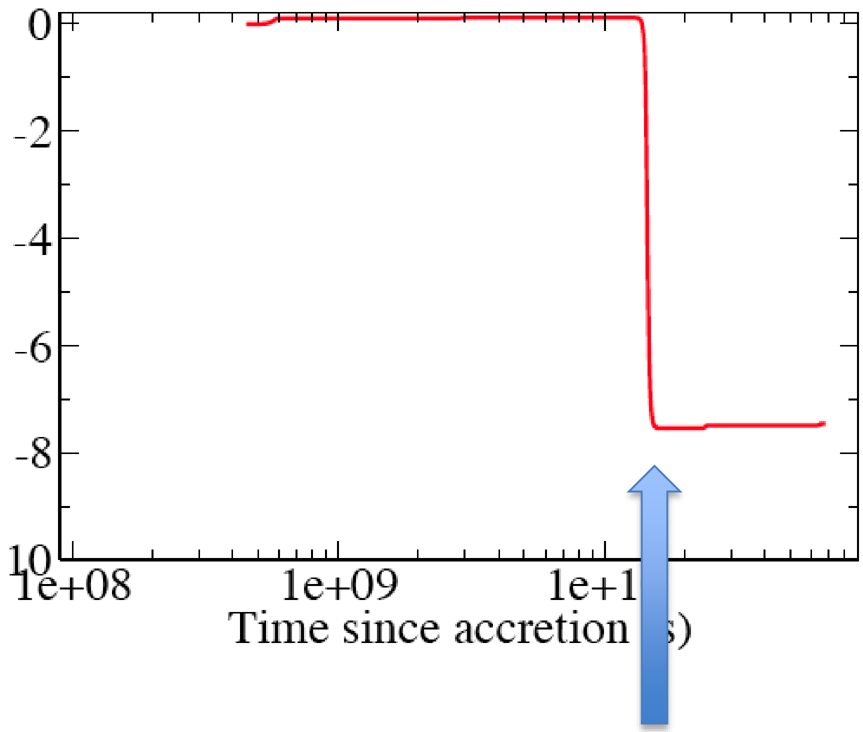

Density: 0.00e+00 g/cm^3
Yn: 7.88e-06
EF_e: 0.00 MeV
EF_n: 0.00 MeV
Max Flow2.21e-11
Known masses
Recent NSCL measurement
FRIB
Known limit of stability

A=56 material in the crust

FRDM mass model



HFB-21 mass model

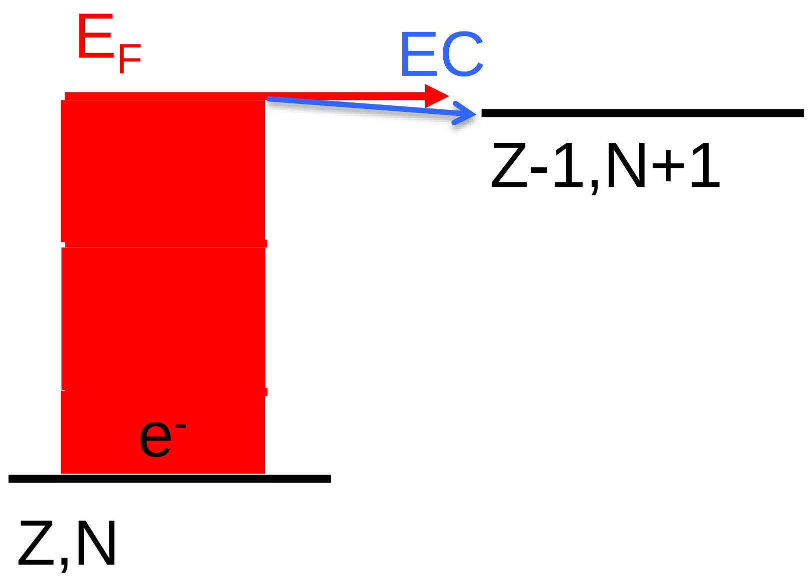


Massive cooling ???

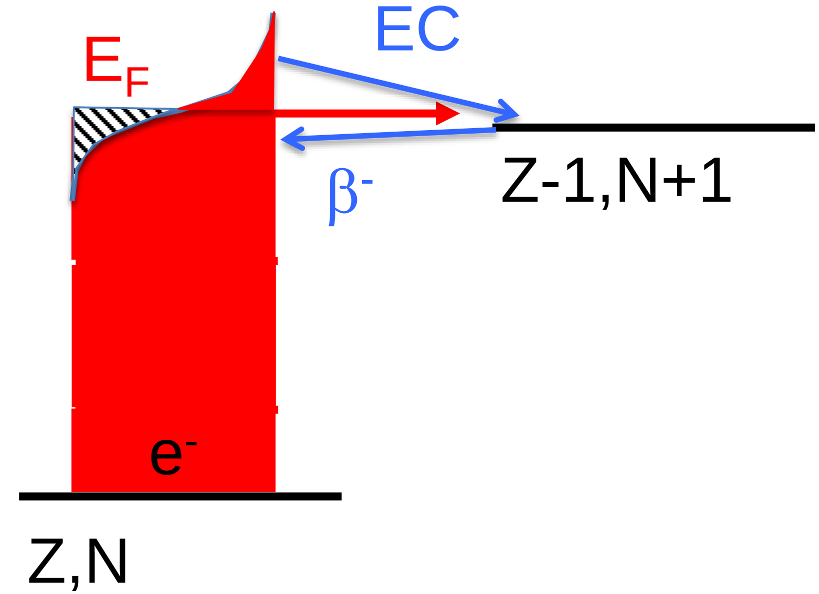
T=0.5 GK

Nuclear Urca process

Zero temperature



finite temperature



Tsuruta & Cameron 1962
for White Dwarfs

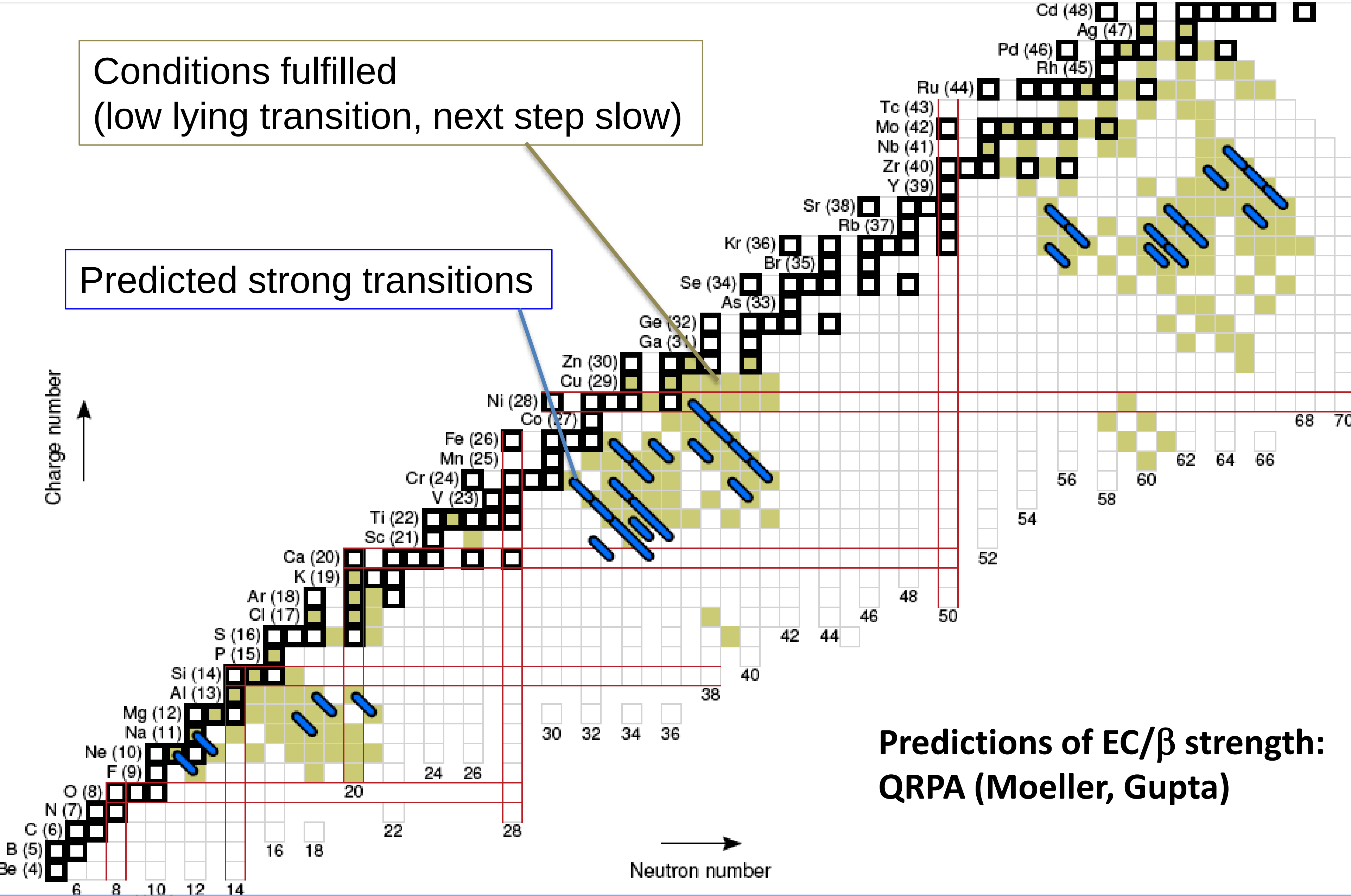
$$(Z,N) + e^- \rightarrow (Z-1,N+1) + \nu_e$$

$$(Z-1,N+1) \rightarrow (Z,N) + e^- + \bar{\nu}_e$$

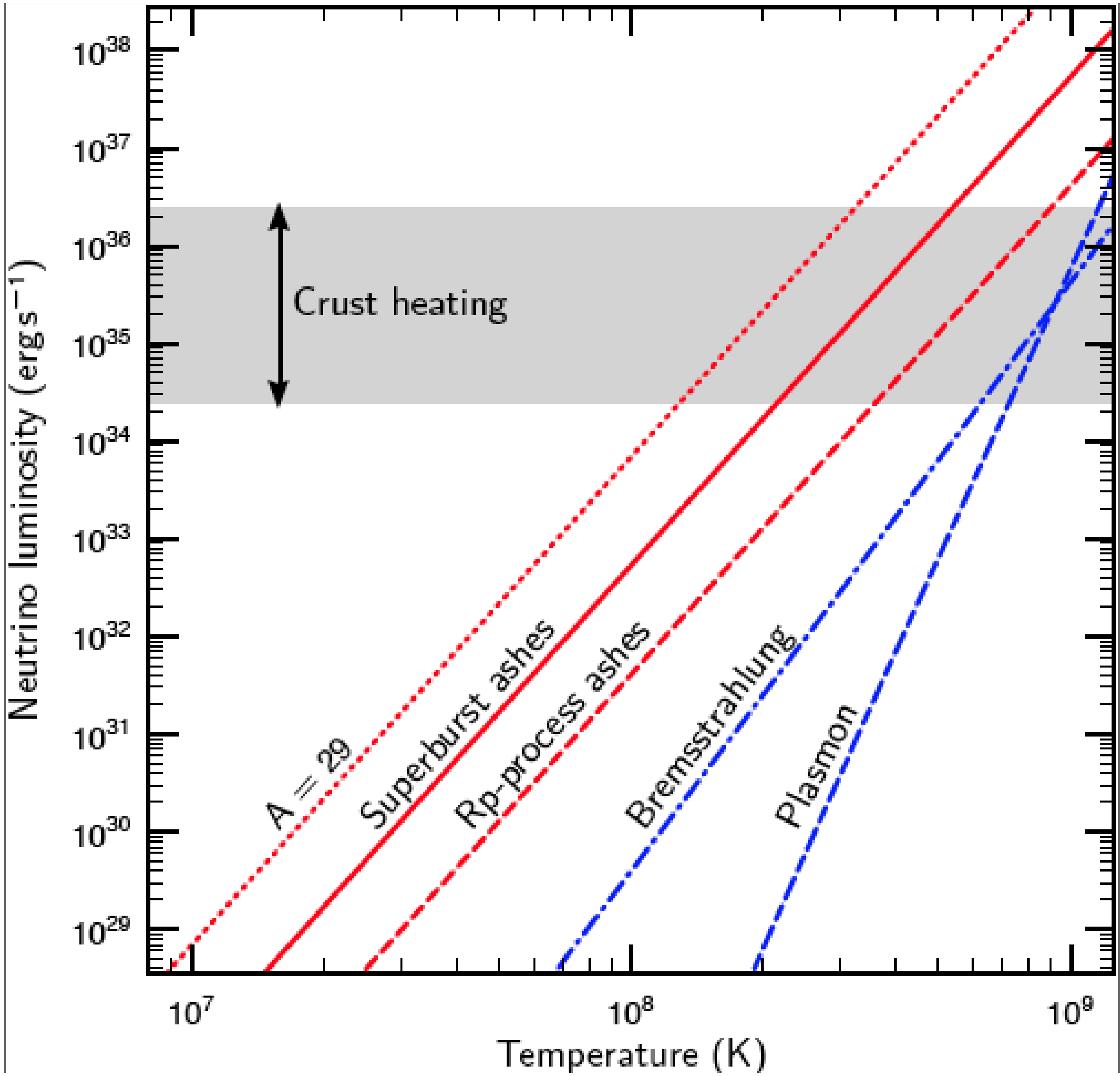
Urca process with nuclei

in thin layer (~1m) at compositional boundary

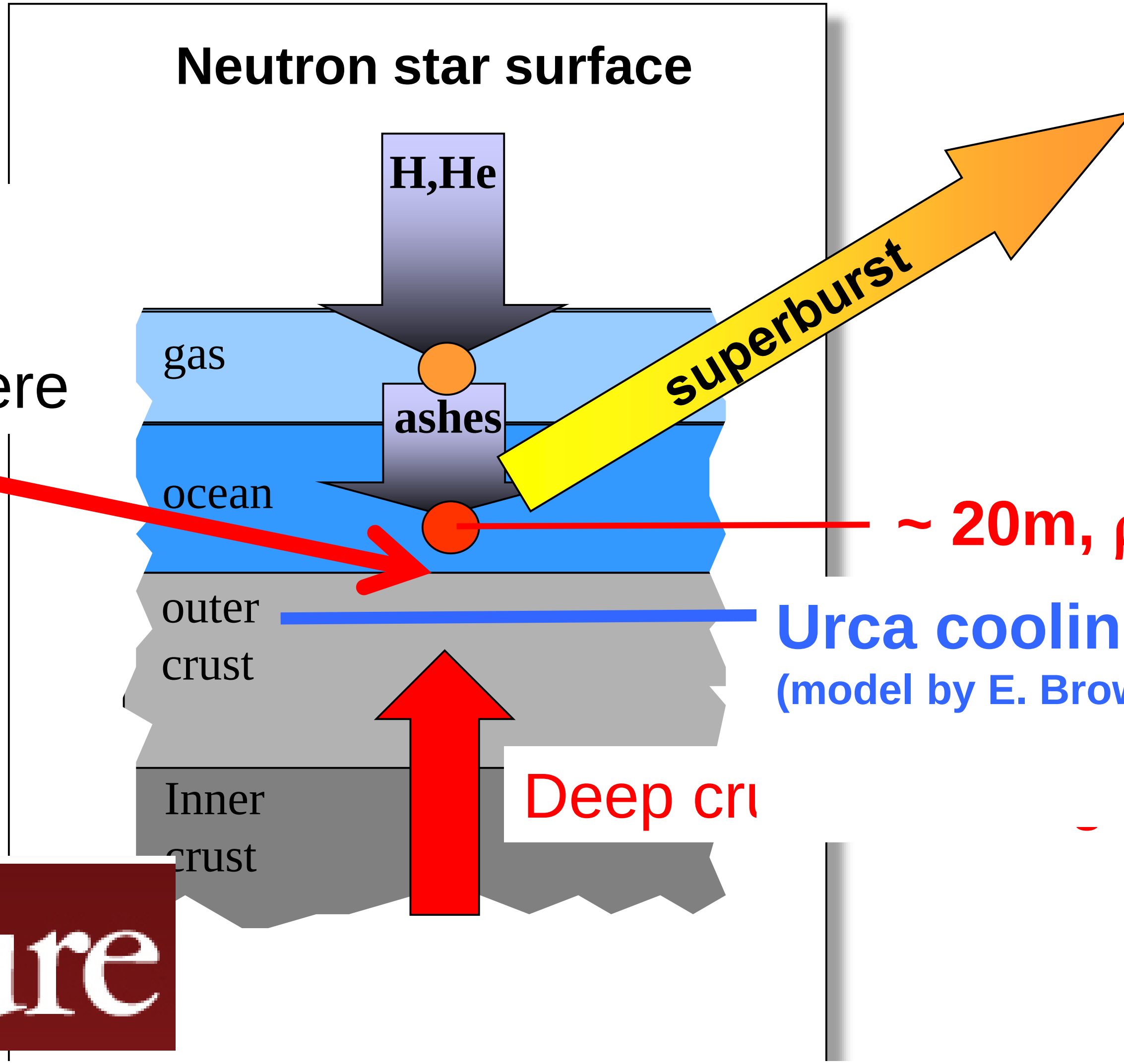
Location of predicted cooling Urca pairs



Predictions of EC/β strength: QRPA (Moeller, Gupta)


Neutrino luminosity (erg s^{-1})
Temperature (K)
Crust heating
A = 29
Superburst ashes
Rp-process ashes
Bremsstrahlung
Plasmon
10^{38}
10^{37}
10^{36}
10^{35}
10^{34}
10^{33}
10^{32}
10^{31}
10^{30}
10^{29}
10^{7}
10^{8}
10^{9}

How can we make the ocean hotter?



Ocean heating must be here

~ 20m, ρ=10^9 g/cm^3

Urca cooling layer shield
(model by E. Brown)

Deep cru

nature

H. Schatz, S. Gupta, P. Möller, M. Beard, E. F. Brown, A. T. Deibel, L. R. Gasques, W. R. Hix, L. Keek, R. Lau, A. W. Steiner & M. Wiescher Nature Letter, AOP December 2, 2013

Summary

- Nuclear astrophysics needs to be done as a cross-disciplinary effort and requires larger collaborations
- Centers such as JINA or NAVI are critical
  - To stimulate and create the collaborative connections
  - To start coordinated efforts

    Example: experimental and observational proposals, with theory projects started at the same time
  - To communicate data and results
  - To educate across field boundaries (classes not effective)
  - To broaden expertise across field boundaries

    Example: astro theorists understand nuclear data

    Example: experimentalists can do simple network calculations
- **Future**: JINA-CEE: Center for the Evolution of the Elements
  - Take advantage of large collaborative network + major developments
  - Focus on Origin of the Elements at low Z, and Dense Matter
  - Augment team
  - Tighter connections, also with NAVI