

nuclear data for astrophysics

resources, challenges, strategies,

& software solutions

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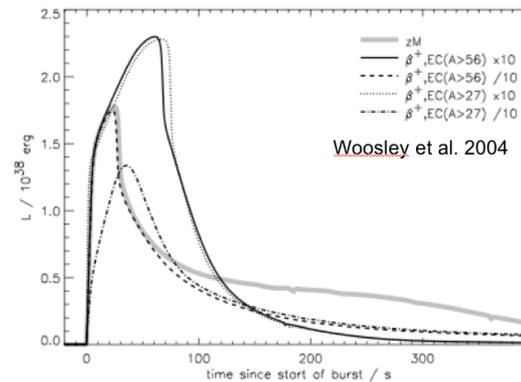
univ. california san diego

san diego, california, usa

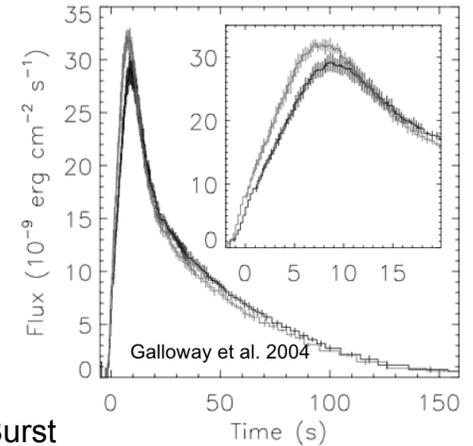
- motivation
- resources
- challenges
- strategies
- manpower
- evaluations
- prioritizations
- visualizations
- coordination

motivation

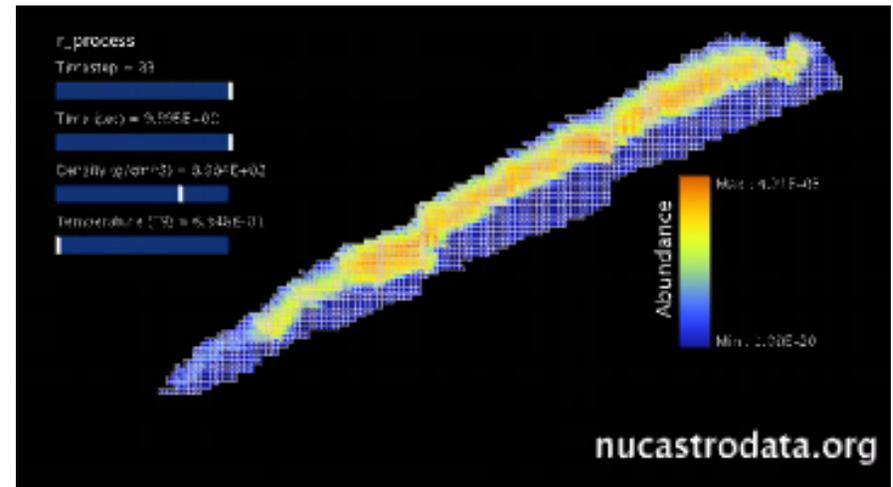
- nuclear astrophysics is an exciting, rapidly growing, interdisciplinary field with tremendous appeal to researchers & general public
- understanding of many fascinating astrophysical phenomena rely on input nuclear data
- compelling questions include:
how do stars evolve and sometimes explode ?



Theoretical
[with different weak rates]



Observation
[RXTE GS1826-24]

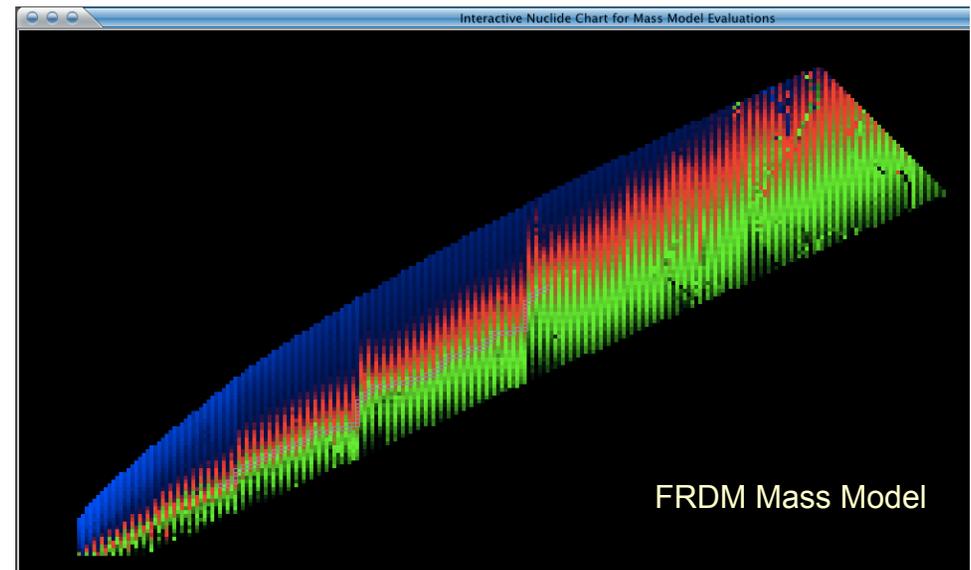
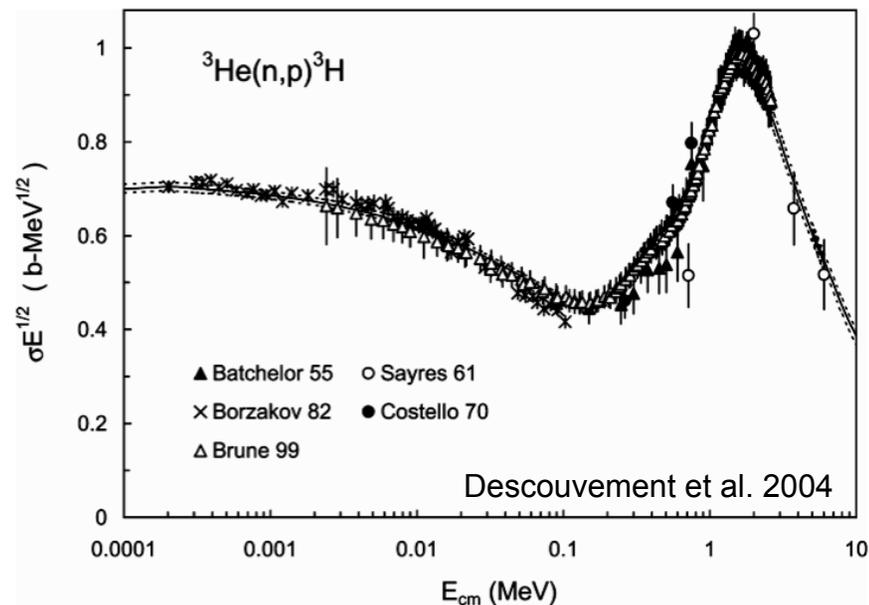


how were the elements formed ?

how did the Universe begin, evolve, & how will it end ?

motivation

- a broad collection of **nuclear physics information** provides an **EMPIRICAL FOUNDATION** to understand a wide range of astro phenomena



- reactions (cross sections, s-factors, reaction rates)
- structure (masses, decays, resonance properties ...)
- other (nuclear equation of state ...)

motivation

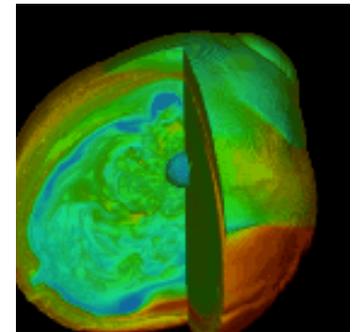
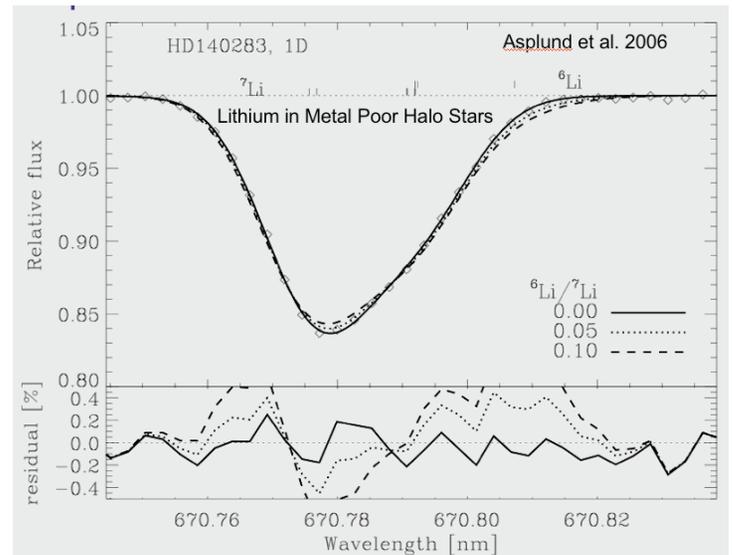
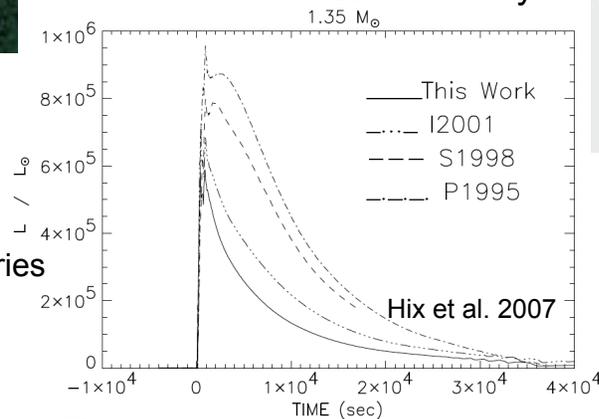


GSI-FAIR



RIKEN RI Beam Factory

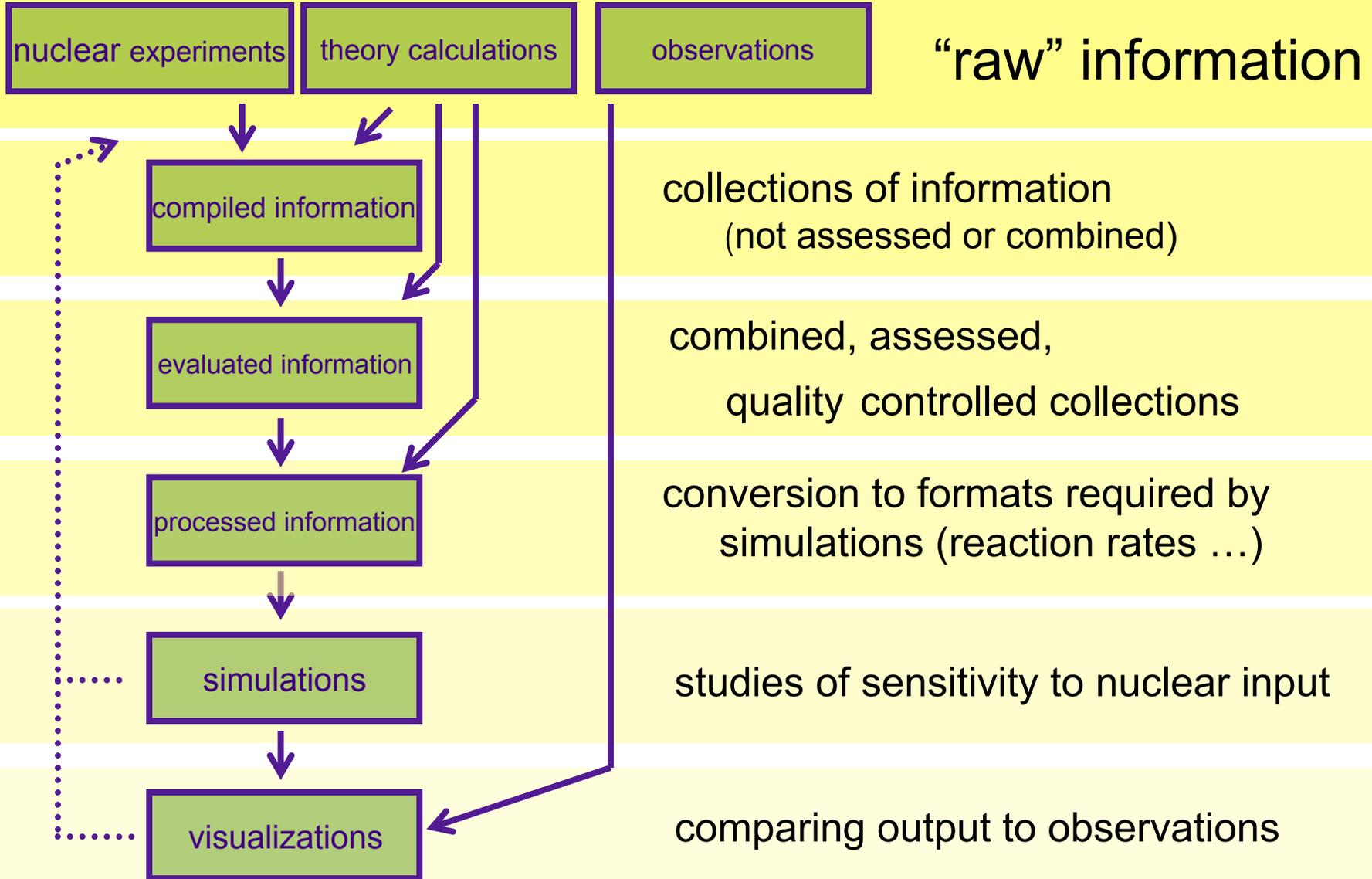
Predicted Nova
Light Curves with
different rate libraries



- many reasons to **EXPAND** nuclear astrophysics data efforts
 - **science drivers**: new facilities promising much more data, better observations, more sophisticated astro simulations, more elaborate *sensitivity studies*
 - **manpower**: excellent way to recruit young scientists into nuclear data work
 - **impact per dollar**: data activities are **inexpensive** and really impact astro work
 - **exposure**: popularity among public brings positive exposure to data activities

background

nuclear data activities for astrophysics



resources

• numerous resources now available online ...

Karlsruhe Astrophysical Database of Nucleosynthesis in Stars

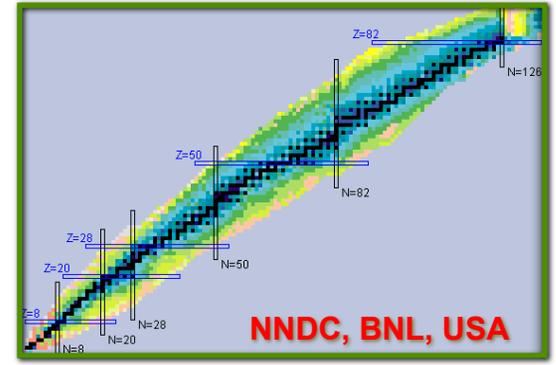
s-process [Standards] [Logbook] [FAQ] [Links] [Disclaimer] [Contact] p-process

KFK, Karlsruhe, Germany

View Maxwellian-Averaged (n,g) Cross Section

Isotope

(Examples: Ba138, Ta180m.)

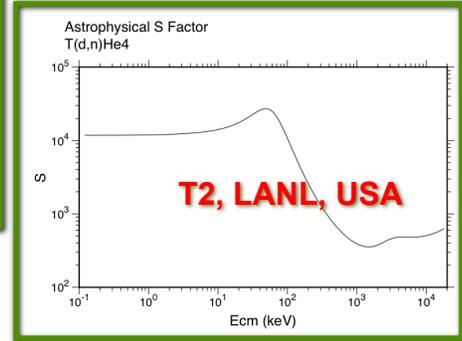
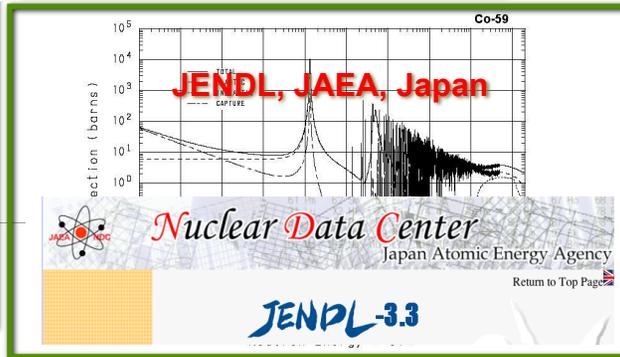



strong and electromagnetic rates, $t_9 = 1.000$ $\rho = 1.000$

z	a	(n,g)	(g,n)	(p,n)	(n,p)	(p,g)	(g,p)	(a,p)	(p,a)	(a,n)	(n,a)	(a,g)	(g,a)
p	28	6.8E+04	5.1E-75	1.8E-53	5.5E+08	2.7E+01	1.9E-05	2.9E-06	1.8E-40	5.6E-24	3.6E+06	7.4E-11	4.8E-43
p	29	8.7E+03	9.7E-44	5.4E-45	5.1E+08	3.5E+00	8.7E-12	3.3E-06	1.6E-26	3.4E-40	3.0E+07	4.6E-10	3.5E-32
p	30	7.3E+05	1.8E-46	2.5E-27	5.6E+08	1.2E+02	4.2E-19	2.0E-06	1.1E-13	4.1E-18	2.7E+07	4.6E-10	1.0E-32
p	31	1.9E+05	1.5E-25	2.7E-23	3.7E+08	1.0E+02	7.9E-33	2.1E-06	1.0E-08	1.3E-21	1.1E+08	1.0E-07	1.8E-32

Reaction Rates for Stellar Nucleosynthesis
R. Hoffman, T. Rauscher, A. Heger, and S. Woosley
LLNL, USA

p	a	(n,g)	(g,n)	(p,n)	(n,p)	(p,g)	(g,p)	(a,p)	(p,a)	(a,n)	(n,a)	(a,g)	(g,a)
p	41	4.3E+03	1.8E+03	1.3E+03	1.8E-63	5.0E-02	1.2E-90	4.7E-11	1.5E-11	5.9E-06	5.7E-54	1.5E-10	3.9E-83
p	42	3.5E+04	3.1E-13	1.5E+03	5.7E-81	6.7E-02	1.3E-92	6.2E-15	1.2E-05	6.9E-06	6.7E-72	9.6E-11	4.1E-78
p	43	9.6E-04	2.7E+09	1.7E+03	3.7E-71	4.2E-02	2.6E-91	4.0E-21	7.6E-03	7.7E-06	3.7E-56	7.2E-11	1.3E-71
p	44	6.7E+03	2.0E+01	2.2E+03	4.8E-99	5.9E-02	2.3E-100	2.4E-17	2.1E-04	1.2E-05	7.4E-79	9.0E-11	4.1E-81
p	45	1.1E+01	2.6E+09	2.1E+03	2.7E-93	3.6E-02	3.9E-106	3.3E-15	1.5E-05	9.1E-06	1.4E-73	7.0E-11	1.3E-85



NACRE People Database Files Links

(p,g) reactions
 dp,gHe3
 Li6(p,g)Be7
 Li7(p,g)Be8
 Comments
 S-factor
 Rate
 Be8 spectrum
 Be7(p,g)Be8
 Be9(p,g)Be10
 B10(p,g)C11
 B11(p,g)C12
 C12(p,g)N13
 C13(p,g)N14
 N13(p,g)O14
 N14(p,g)O15
 N15(p,g)O16
 O16(p,g)F17
 O17(p,g)F18
 O18(p,g)F19
 F19(p,g)Ne20
 Ne20(p,g)Na21
 Ne21(p,g)Na22
 Ne22(p,g)Na23
 Na22(p,g)Mg23
 Na23(p,g)Mg24

NACRE, ULB, Belgium

E (MeV)	sigma (b)	error (b)	S-factor (MeV b)	error (MeV b)	REF
1.49	5.55E-05	5.6E-05	8.11E-04	8.11E-04	RI63
1.57	5.92E-05	5.9E-05	8.59E-04	8.59E-04	

 * Na<sig v> [mol-1 cm3 s-1] for p-capture on Ni 58 *

 T9 Ni 58 Ni 57 Ni 56 Cu 65 Cu 64
 0.01 0.0618E-01 0.0000E+00 0.0000E+00
 0.05 3.3258E-29 9.9999E-99 9.9999E-99
 0.10 5.8591E-20 9.9999E-99 9.9999E-99
 0.20 1.7044E-01 0.0000E+00 1.5000E-01

BRUSLIB, UI B, Belgium

Nuclear Astrophysics Data

BRUSLIB: the Brussels Nuclear Library for Astrophysics Applications

- Nuclear Reaction Rates:** The European Nuclear Astrophysics Compilation of REaction Rates
 - Link to NACRE home page
 - Non-explosive hydrogen and helium burnings: Abundance predictions from the NACRE reaction rates. *Color version of the paper published in Astronomy & Astrophysics 347, 572 (1999)*
 - Postscript file
 - PDF file
- Masses and Fission Barriers**
- Nuclear level densities**
- Hauser-Feshbach rates**
- Partition functions**

4.00	1.9667E+03	9.9165E-03	4.2767E-01
4.50	3.1685E+03	2.2038E-01	4.2047E+00
5.00	4.6649E+03	2.6208E+00	2.7918E+01
5.50	6.3920E+03	1.9659E+01	1.3625E+02
6.00	8.2557E+03	1.0386E+02	5.1902E+02
7.00	1.1963E+04	1.3497E+03	4.2708E+03
8.00	1.5051E+04	8.6265E+03	2.0475E+04
9.00	1.7146E+04	3.4376E+04	6.8731E+04
10.00	1.8208E+04	9.9102E+04	1.8213E+05

Java Interface to the NON-SMOKER database

With this applet you can view plots of cross sections and reaction rates. Please read the documentation for this calculations! You have to activate Java in your browser in order to run the applet. To just get a table of cross sections, click on the interface.

EICM cu59 n+ cu58 he4+ co55

0.20050	4.338E-21	0.000E+00	0.000E+00
0.20778	1.236E-20	0.000E+00	0.000E+00
0.21645	4.010E-20	0.000E+00	0.000E+00
0.22677	1.487E-19	0.000E+00	0.000E+00
0.23905	6.317E-19	0.000E+00	0.000E+00
0.25368	3.072E-18	0.000E+00	0.000E+00

log10(Cross section [b])

NON-SMOKER, Basel, Switzerland

Element: ni Massnumber: 58

Type: Reaction: Mass:

Cross Sections (p,g) FRDM

Plot Clear Reset

Separate plot window Cumulate plots

nuclear astrophysics data

ND2007

Michael Smith ORNL

resources

http://www.nucastrodata.org/datasets.html

nucastrodata.org usnuclearscience.org Google Image bigbangonline.org ariaweb.org ORNL RIB Astro ORNL Physics God

NUCASTRODATA.ORG

WELCOME — DATASETS — INFRASTRUCTURE

Reaction Rate Collections with Combined Experimental & Theoretical Rates

Evaluated Experimental Reaction Rate Collections

Theoretical Reaction Rates

Weak Reaction Rates

S-factors

Experimental & Evaluated Cross Sections

Theoretical Cross Sections

NACRE Charged Particle-Induced Reaction Cross Sections 1999 - Angulo et al., Nacre Collb. [ULB]

Evaluated Nuclear Data File - US National Nuclear Data Center [US NNDC]

Cross Section Information Storage Retrieval Service (CSISRS) Nuclear Data Center - US National Nuclear Data Center [US NNDC]

Evaluated Nuclear Data Library (ENDL) plots and ENDF, IEF, and IFNL plots

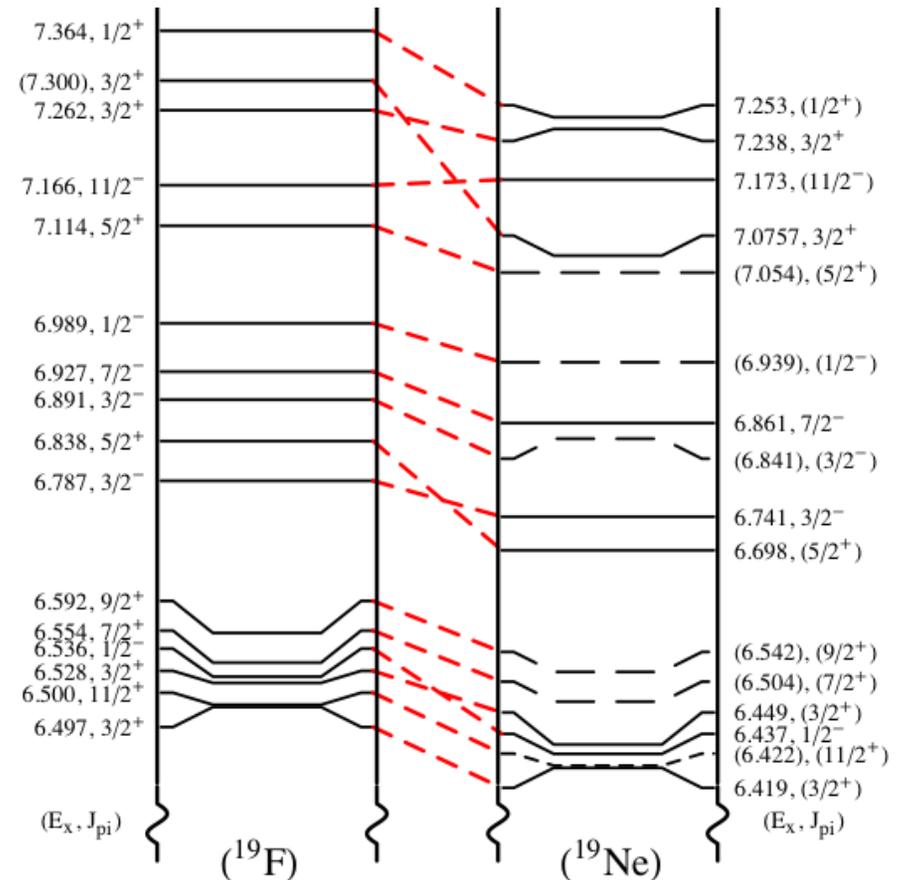
challenges

- current efforts are overwhelmingly independent, **small scale**, voluntary, under- and haphazardly- funded, driven by specific research projects

→ **lack continuity, completeness, coordinated vision**

- **very long time** between lab measurements & incorporation into “leading” databases / compilations
 - last “official, public” update of REACLIB [including experimental rates] was in 1995

→ astro modelers are using **outdated nuclear input**



challenges

- competition → information not being shared
 - rate libraries held as “**proprietary**”
 - rate errors not communicated to fellow researchers
 - duplication of efforts due to lack of communication

- lack of standards

→ intercomparison of simulations difficult

- inadequate visualization

→ impedes progress
& frustrates researchers

- dwindling evaluation manpower

→ no one group can provide all needed data;
many astro data needs are not being met
CRISIS: most full time US evaluators will retire within a decade

strong and electromagnetic rates, $t_9 = 1.000$ rho = 1.00E+00

z	a	(n,g)	(g,n)	(p,n)	(n,p)	(p,g)	(g,p)	(a,p)	(p,a)	(a,n)	(n,a)	(a,g)	(g,a)
p	28	6.8E+04	5.1E-75	1.8E-53	5.5E+08	2.7E+01	1.9E-05	2.9E-06	1.8E-40	5.6E-24	3.6E+06	7.4E-11	4.8E
p	29	8.7E+03	9.7E-44	5.4E-65	5.1E+08	3.5E+00	8.7E-12	3.3E-06	1.6E-26	3.4E-40	3.0E+07	4.6E-10	3.5E
p	30	7.3E+05	1.8E-46	2.5E-27	5.6E+08	1.2E+02	4.2E-19	2.0E-06	1.1E-13	4.1E-18	2.7E+07	4.6E-10	1.0E
p	31	1.9E+05	1.5E-25	2.7E-23	3.7E+08	1.0E+02	7.9E-33	2.1E-06	1.0E-08	1.3E-21	1.1E+08	1.0E-07	1.8E
p	32	1.3E+06	7.2E-35	9.7E+02	1.0E-01	2.9E+01	4.0E-37	1.3E-07	2.4E-05	2.1E-06	5.0E-01	5.2E-08	1.1E
p	33	3.1E+05	7.6E-17	1.1E+03	2.7E+05	8.8E+01	4.7E-43	1.8E-06	6.4E-03	4.6E-08	1.7E+05	1.0E-06	9.5E
p	34	3.7E+05	7.0E-27	1.6E+03	3.5E-20	8.6E-01	5.5E-49	3.5E-14	2.5E-01	2.6E-06	9.9E-14	1.6E-09	1.5E
p	35	2.9E+04	6.9E-04	1.6E+03	5.7E-14	6.5E-01	2.5E-56	3.0E-15	5.5E+00	2.7E-06	1.4E-02	1.2E-08	3.0E
p	36	2.0E+05	4.7E-19	1.7E+03	2.6E+45	2.5E-01	1.9E-61	2.0E-13	6.5E-03	3.3E-06	3.3E-25	3.6E-10	2.1E
p	37	3.2E+04	3.1E-04	1.5E+03	4.8E-34	1.2E-01	1.9E-67	5.9E-11	5.2E-05	3.1E-06	8.3E-21	4.4E-10	1.4E
p	38	1.5E+05	2.3E-16	1.3E+03	2.1E-55	1.5E-01	1.1E-71	5.1E-11	7.5E-07	5.6E-06	1.8E-41	3.2E-10	1.2E
p	39	4.4E+04	3.4E-05	1.2E+03	5.7E-47	8.2E-02	2.3E-79	1.5E-10	2.6E-08	5.3E-06	1.3E-39	2.9E-10	5.3E
p	40	2.4E+04	1.1E-08	1.4E+03	4.9E-66	1.1E-01	6.7E-80	1.0E-11	1.1E-07	6.7E-06	1.6E-55	2.6E-10	1.1E
p	41	4.3E+03	1.8E+03	1.3E+03	1.9E-63	5.0E-02	1.2E-90	4.7E-11	1.5E-11	5.9E-06	5.7E-54	1.5E-10	3.9E
p	42	3.5E+04	3.1E-13	1.5E+03	5.7E-81	6.7E-02	1.3E-92	6.1E-15	1.2E-05	6.9E-06	6.7E-72	9.6E-11	4.1E
p	43	9.6E-04	2.7E+09	1.7E+03	3.7E-71	4.2E-02	2.6E-91	4.0E-21	7.6E-03	7.7E-06	3.7E-56	7.2E-11	1.3E
p	44	6.7E+03	2.0E+01	2.2E+03	4.8E-99	5.9E-02	2.3-100	2.4E-17	2.1E-04	1.2E-05	7.4E-79	9.0E-11	4.1E
p	45	1.1E+01	2.6E+09	2.1E+03	2.7E-93	3.6E-02	3.9-106	3.3E-15	1.5E-05	9.1E-06	1.4E-73	7.0E-11	1.3E

strategies

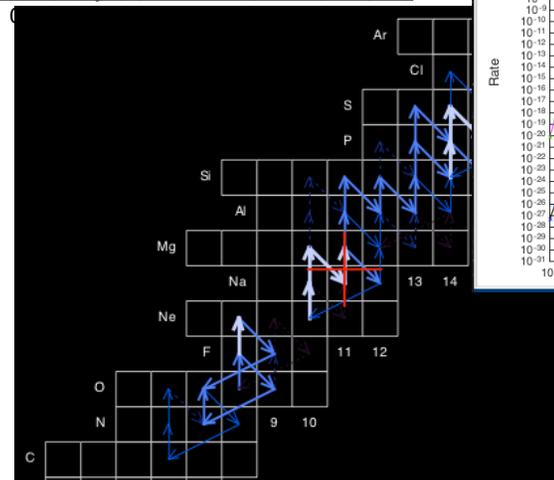
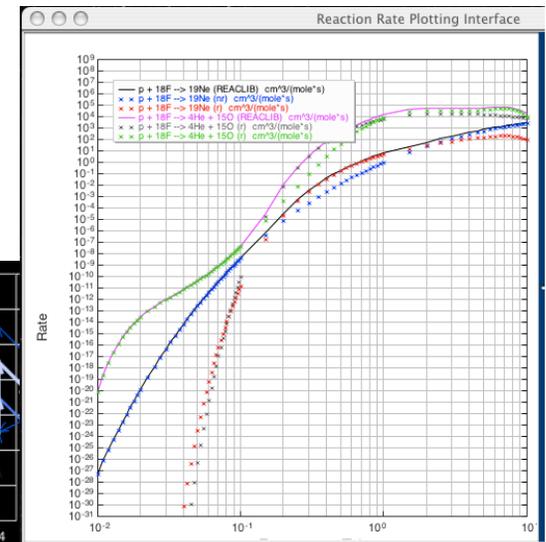
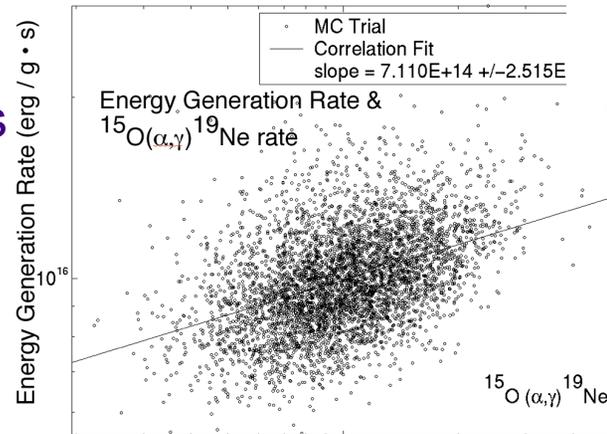
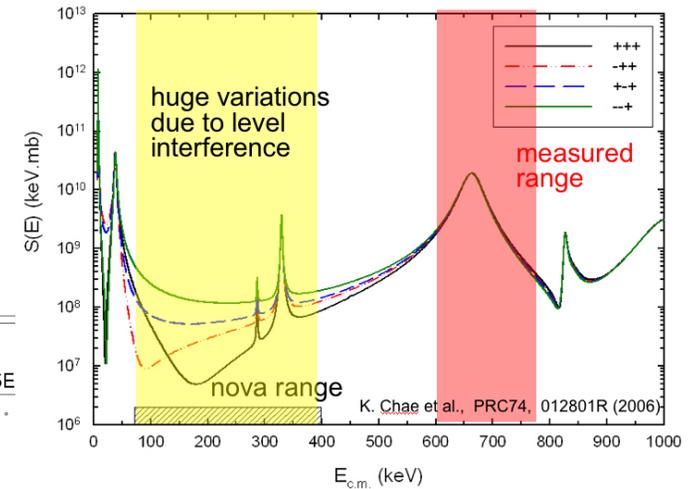
[1] boost evaluation manpower

[2] streamline evaluations

[3] prioritize efforts

[4] develop enhanced visualization tools

[5] improve communication & coordination on an international scale



evaluation manpower

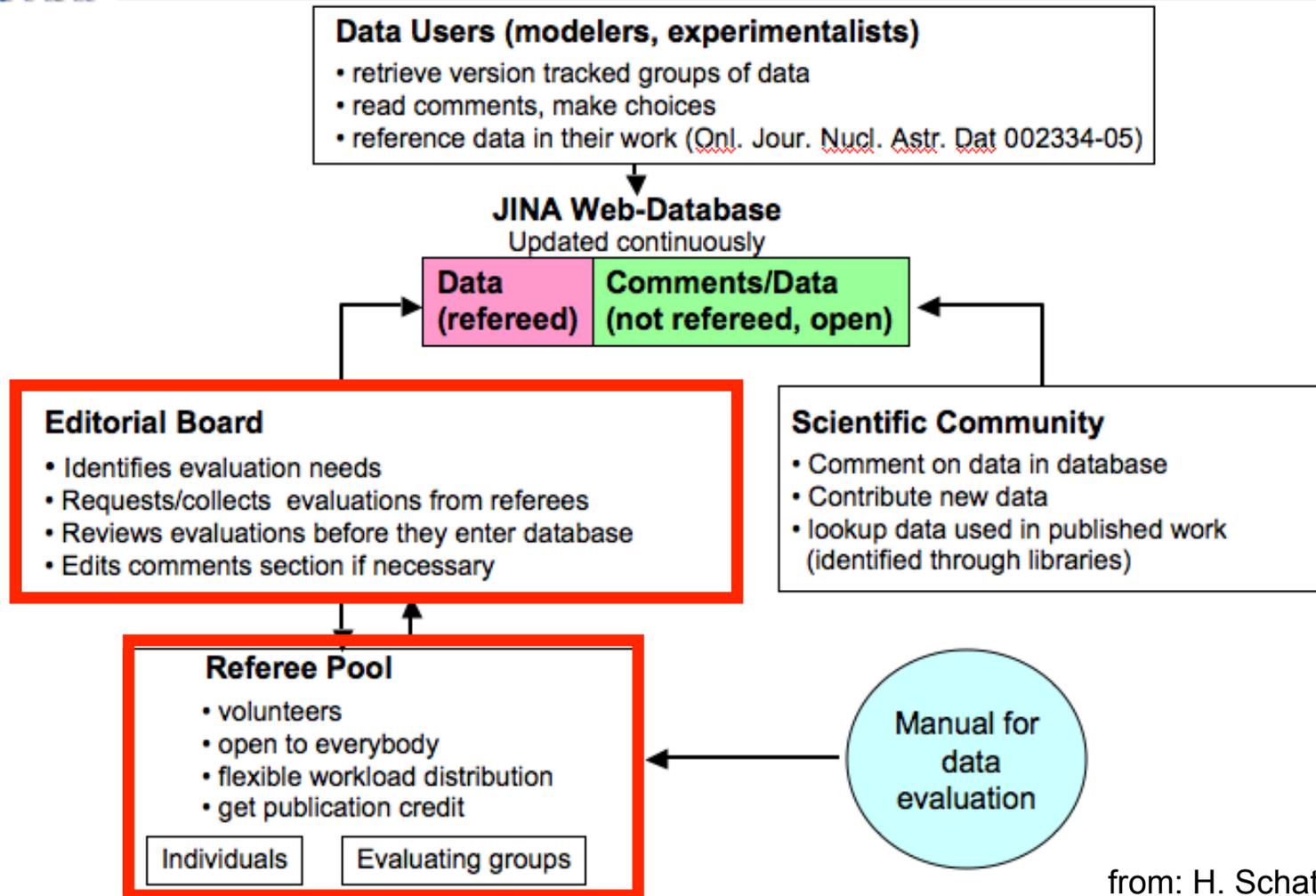
- goal: ensure there is a **next generation of evaluators**
- combination of new hires & diversion of existing effort
- recruit from nuclear data & nuclear research communities
- make positions more appealing with half-time research, half-time data work
- approach
 - transfer knowledge from experienced evaluators to new hires - **mentoring**
 - give credit to evaluators & properly disseminate their work
 - peer review work of evaluators
 - develop evaluation “**standards**”
 - flexibility on evaluations formats
 - learn from difficulties in previous initiatives
 - **attitude shift** - evaluations considered part of the experimental process

evaluation manpower



The Joint Institute for Nuclear Astrophysics

JINA Online Journal for Nuclear Data - Vision



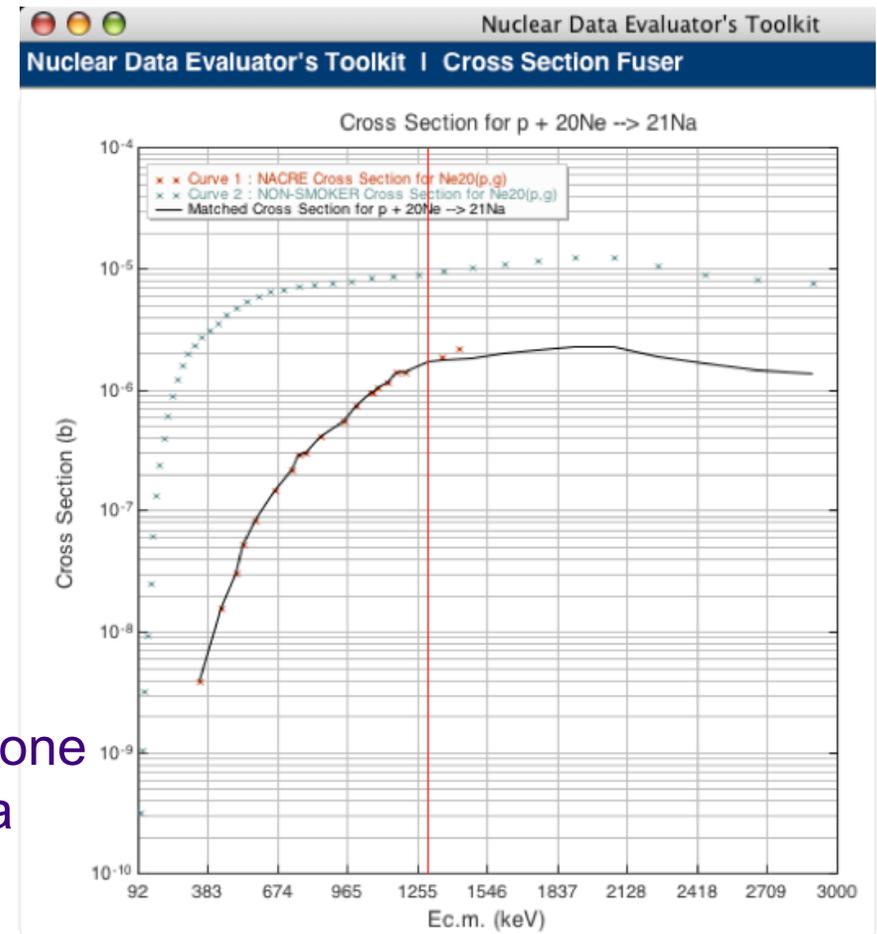
from: H. Schatz, MSU

streamlining evaluations

- reaction & structure evaluations ideally take a **complete** look at all reaction channels, all levels in all nuclei with the same mass ...
- this usually generates much information **never used** in astro simulations
- pace of evaluations can be increased by **simplifying / customizing** for astrophysics
- focus on determining parameters / properties such as
 - properties of levels < 2 MeV above particle thresholds
 - low spin states with single particle nature
 - total cross sections (not differential or partial)
 - note: uncertainties are absolutely essential [especially for sensitivity / Monte Carlo studies]
- important: these shortcuts can only be done if **consistency** is maintained

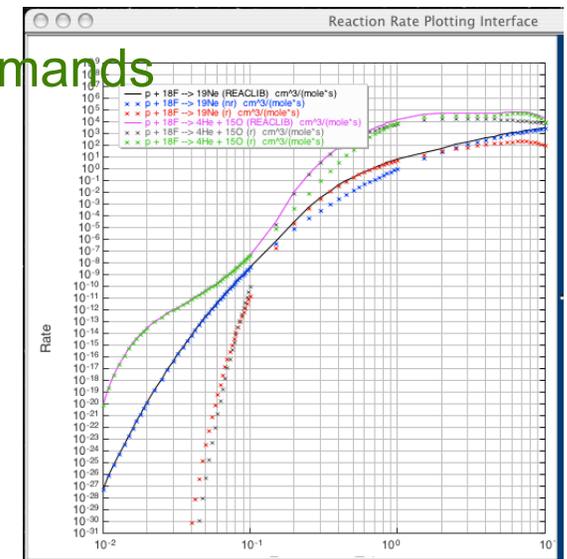
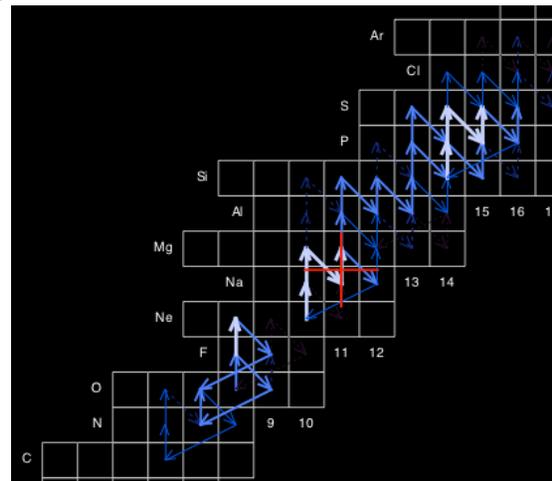
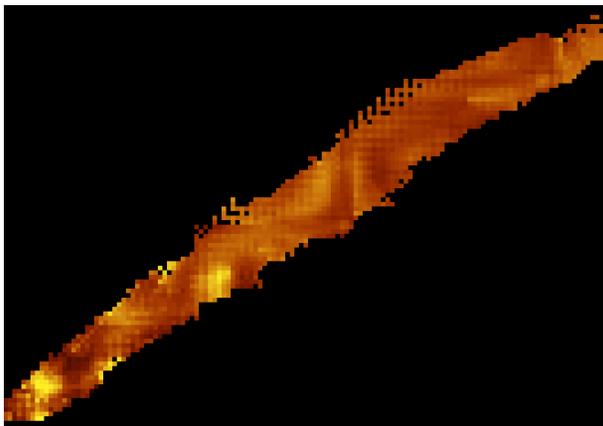
streamlining evaluations

- pace of evaluations also increased by **automating** time-consuming, repetitive tasks:
 - store, renormalize, combine, plot, extrapolate cross sections & s-factors
 - numerically integrate cross sections & s-factors to get reaction rates
- parameterize reaction rates or generate values on a temp grid
- plot & modify reaction rates
- insert rates into new or existing rate libraries
- create, store, modify, document, & merge rate libraries
- major milestone: development of an **online software package** letting anyone perform these tasks on their own data



streamlining evaluations

- **Computational Infrastructure for Nuclear Astrophysics** at nucastrodata.org
 - online software suite -- first **pipeline** from lab results to astro simulations
 - include file manipulation / management, processing, simulations, viz, sharing (community building), commenting (consensus building)
 - Users in 53 institutions in 18 countries
 - online at nucastrodata.org
 - new features continuously added to meet User demands



streamlining evaluations

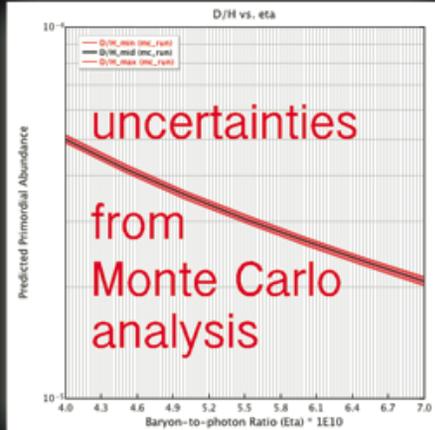
- a new online software package for **early universe studies**

BIG BANG ONLINE

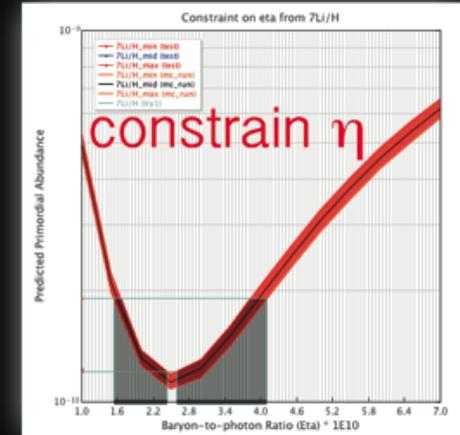
NEW!

custom big bang nucleosynthesis calculations

bigbangonline.org



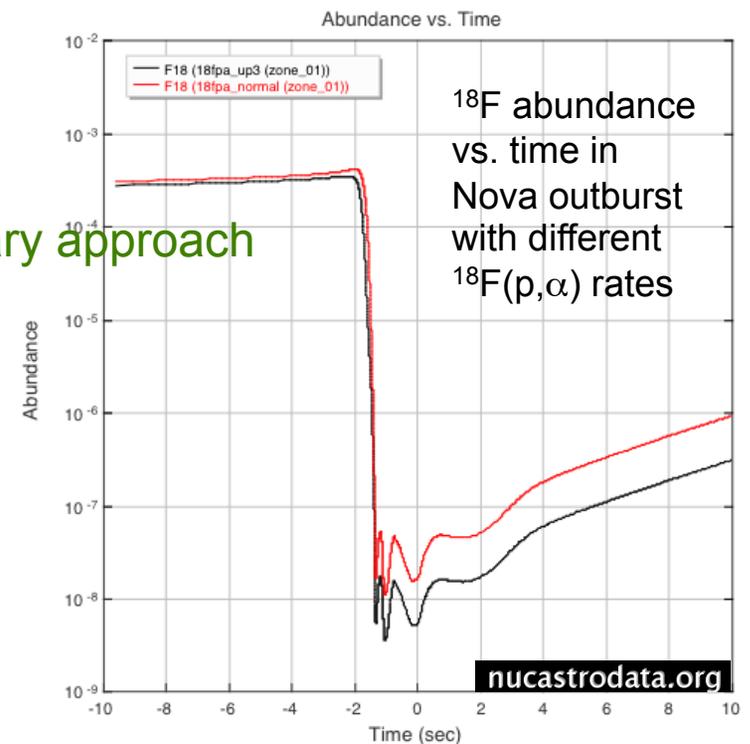
- calculate & visualize light abundances vs. baryon/photon ratio η
- constrain η using observed primordial abundances



for more info write coordinator@bigbangonline.org

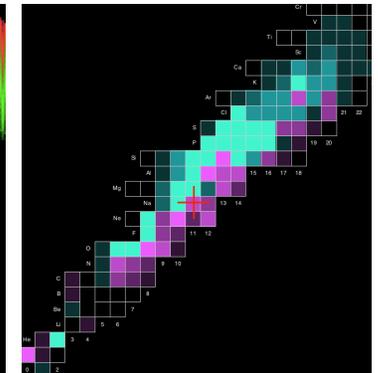
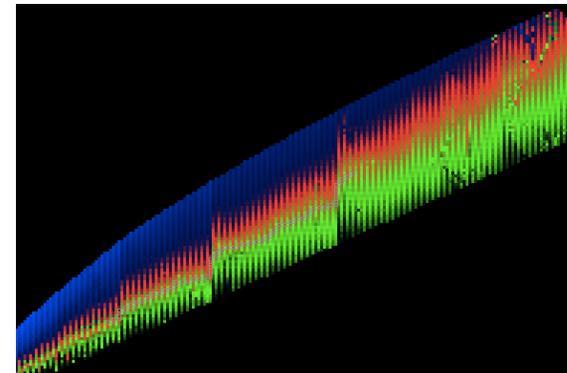
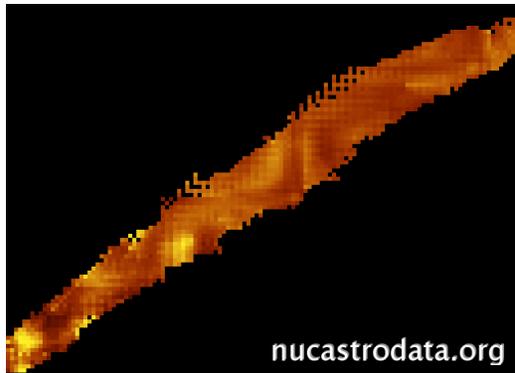
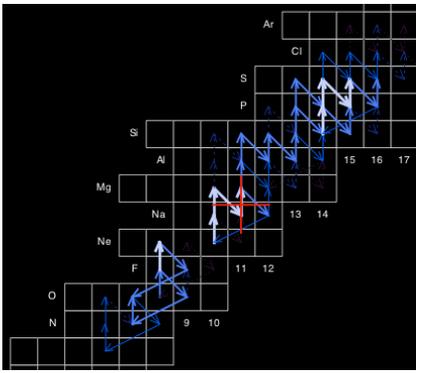
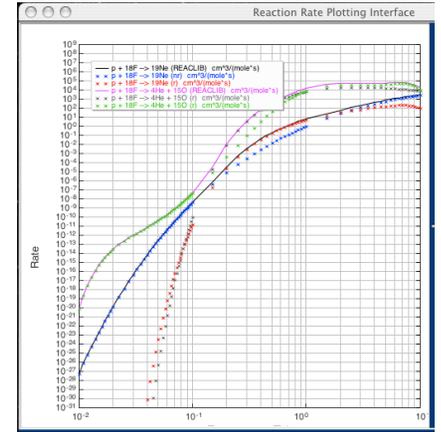
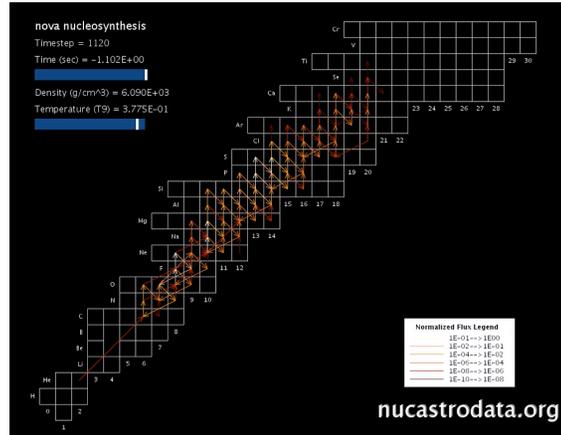
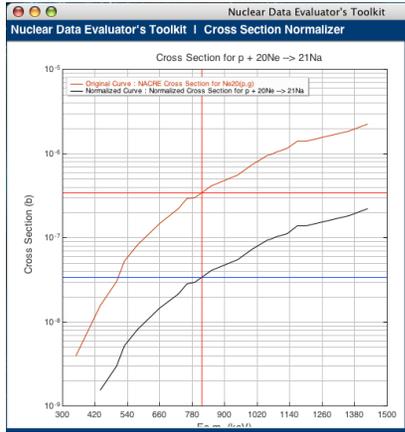
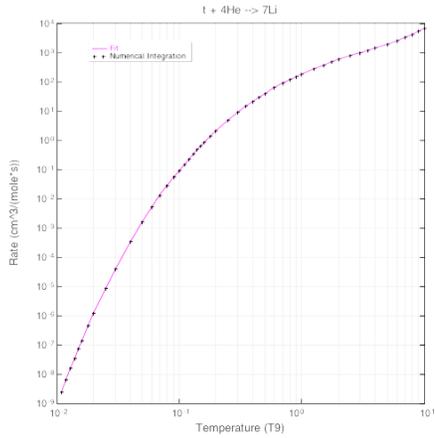
prioritization

- absolutely essential to **prioritize** evaluation projects, especially with limited manpower
- **primary criteria: impact** of new nuclear information on **astrophysical simulations**
- approach:
 - study the **sensitivity** of simulation predictions on input nuclear data
 - develop **software** to facilitate these studies
 - mechanism for sharing simulation results crucial
 - enhanced visualization tools also essential
 - Monte Carlo techniques offer new, complementary approach
- future:
 - vigorously pursue sensitivity studies w/ more sophisticated models [need uncertainties!]
 - develop & maintain more advanced visualization tools



visualization

- majority of online datasets have limited (or no) visualization tools
- this impedes research & frustrates practitioners
- evaluations & sensitivity studies can tremendously benefit from **enhanced visualization**
- new tools are appearing online, and **more are needed ...**



communication & coordination

- many reasons to improve coordination & communication between astro data efforts
 - avoid duplication of limited manpower
 - transfer knowledge to a new generation of evaluators
 - foster collaborative efforts to most effectively use limited resources
 - publicize new techniques and codes to assist other evaluators
 - report on work in progress, broadcast latest results
 - disclose errors in widely-used databases
- communication / coordination enhanced in the US since 1995 via the Astrophysics Task Force of the U.S. Nuclear Data Project
- still crucial to do this on an **international scale**
- software solutions may help ...

communication & coordination

- recent progress
 - **ad-hoc Working Group** formed in 2006 to examine the status of nuclear data for nuclear astro studies and recommend a path forward
 - met in Basel & Geneva in June 2006; next meeting is in Trento in May 2007
 - members include researchers from institutions in the **U.S.** [BNL/NNDC, UND, LLNL, MSU, ORNL], **Brussels**, & **Germany**
 - items being discussed include
 - updating popular reaction rate databases [**REACLIB**]
 - dissemination strategies
 - enlisting help for rate evaluations
 - **software: online forum** for nuclear astrophysics data activities to support the working group - and open to all - established at **nucastrodata.org/forum**
- future: obtain **funding** for the recommended activities of this WG

summary & outlook

- many reasons to **EXPAND** existing **nuclear astrophysics data efforts**
 - scientific (new facilities, simulations, sensitivity studies)
 - resources (recruitment)
 - high impact per dollar, excellent **exposure** for nuclear science
- numerous **challenges** must be overcome:
limited manpower, overwhelming data needs, competition & lack of data sharing, poor viz tools, lack of standards and public data sets ...
- **strategies** addressing these issues include:
 - boost manpower recruiting with incentives
 - streamline evaluations - customize for astrophysics
 - using **software packages** to speed evaluations
 - boost visualization of datasets & simulations
 - vigorously pursuing **sensitivity studies** - prioritize work
 - pursue new mechanisms to **coordinate** activities on international scale
- **goal: help ensure a sustainable future** for this important work

