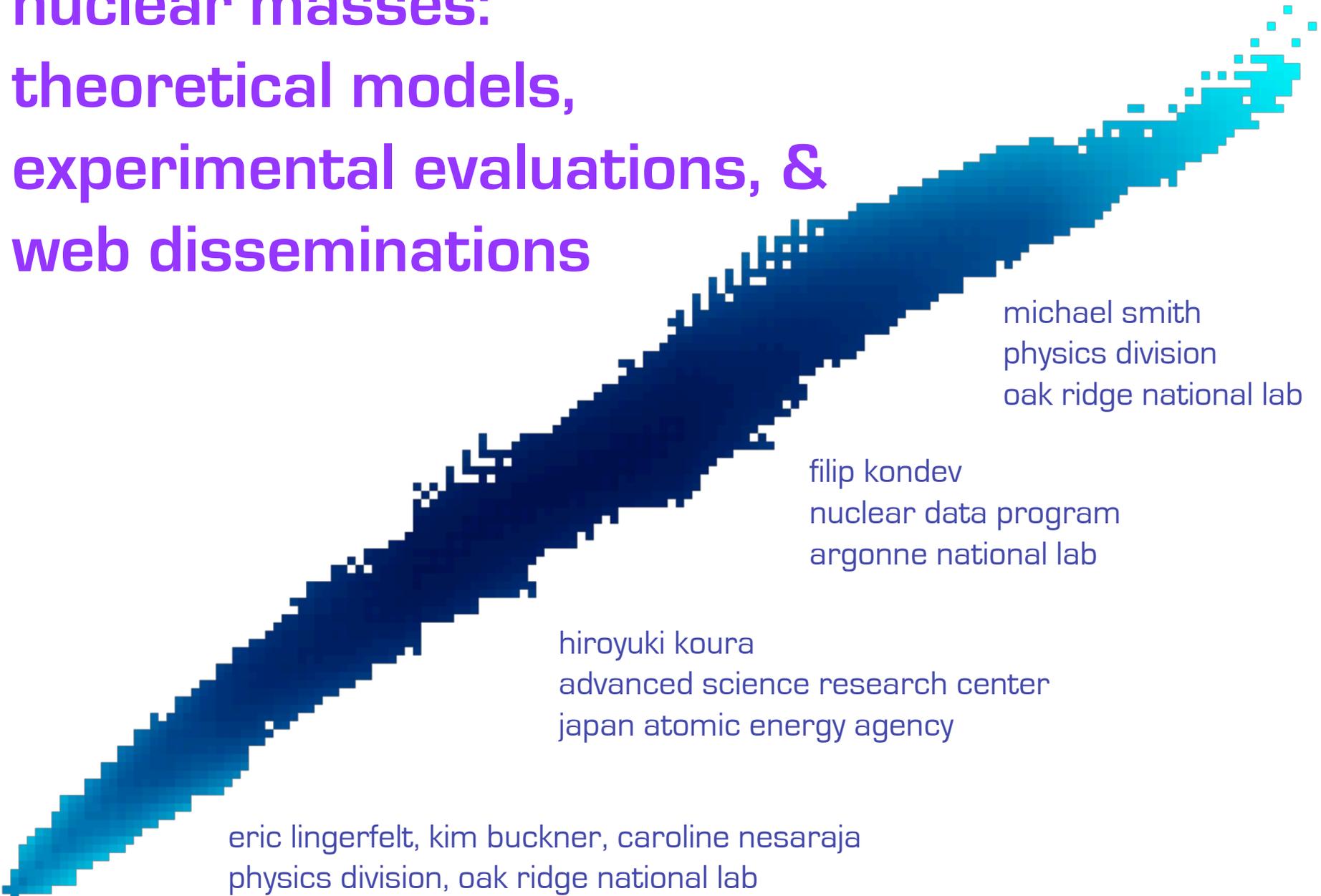


# nuclear masses: theoretical models, experimental evaluations, & web disseminations



michael smith  
physics division  
oak ridge national lab

filip kondev  
nuclear data program  
argonne national lab

hiroyuki koura  
advanced science research center  
japan atomic energy agency

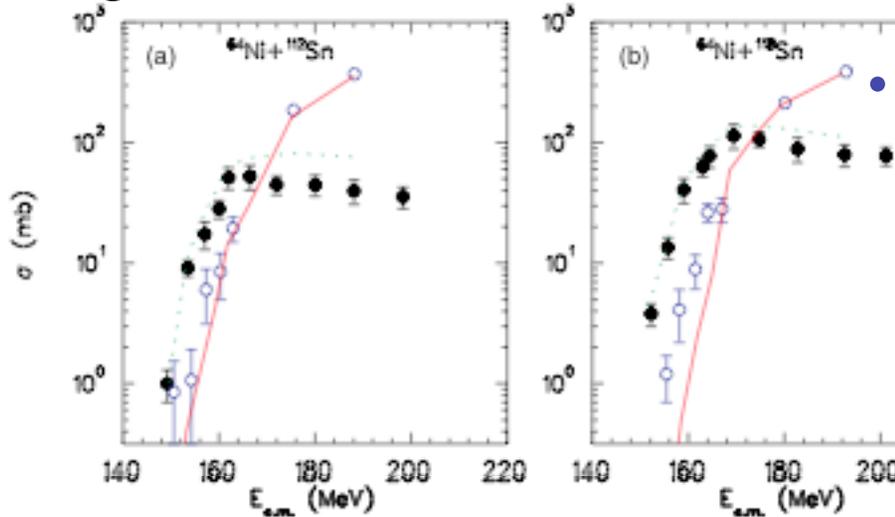
eric lingerfelt, kim buckner, caroline nesaraja  
physics division, oak ridge national lab  
dept. of physics & astronomy, univ. tennessee

# motivation

nuclear masses are important if you ..

- develop nuclear models - especially far from stability, superheavies...

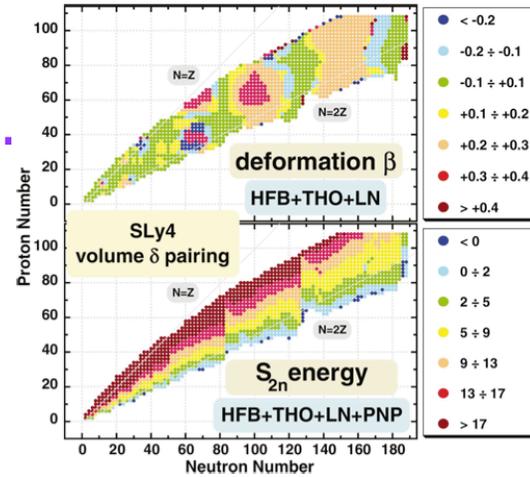
FUSION OF RADIOACTIVE  $^{132}\text{Sn}$  WITH  $^{64}\text{Ni}$   
Liang et al.



- calculate the elements synthesized in the r-process in supernovae

M. V. STOITSOV *et al.*

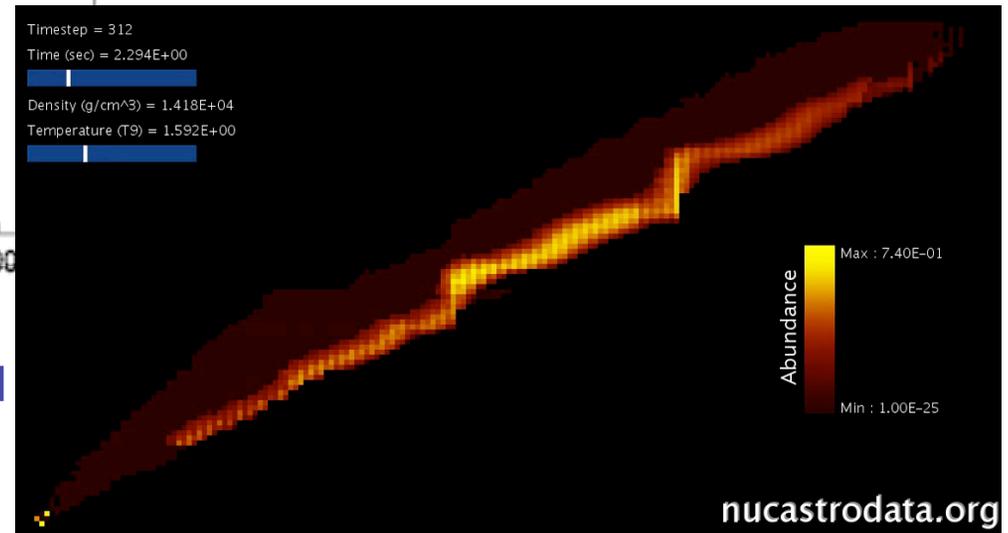
PHYSICAL REVIEW C 68, 054312 (2003)



Stoitsov *et al.*

FIG. 2. (Color) Quadrupole deformations  $\beta$  (upper panel) and two-neutron separation energies  $S_{2n}$  in MeV (lower panel) of particle-bound even-even nuclei calculated within the HFB+THO method with Lipkin-Nogami correction followed by exact particle-number projection. The Skyrme SLy4 interaction and volume contact pairing were used.

- estimate reaction cross sections & calculate energies of reaction products



... or study MANY other problems in nuclear science

nuclear masses: models, evaluations, disseminations michael smith ornl

# nuclear masses: research activities

- measurements

traps                      transfer reactions              mass separators  
storage rings              time of flight                      exotic beam facilities

- theoretical models

algebraic [IMME, Garvey-Kelson relations]  
microscopic - macroscopic [FRDM, Liquid drop]  
microscopic [HFB, RMF, ETFSI]

sophistication &  
agreement with  
experimental masses  
continually improving

- mass evaluations

*not a mere compilation* of experimental values

*complex least-squares optimization* of experimental  
& estimated data using many relations

- disseminations

how to get experimental, evaluated, & theoretical masses out to the community

D. Lunney

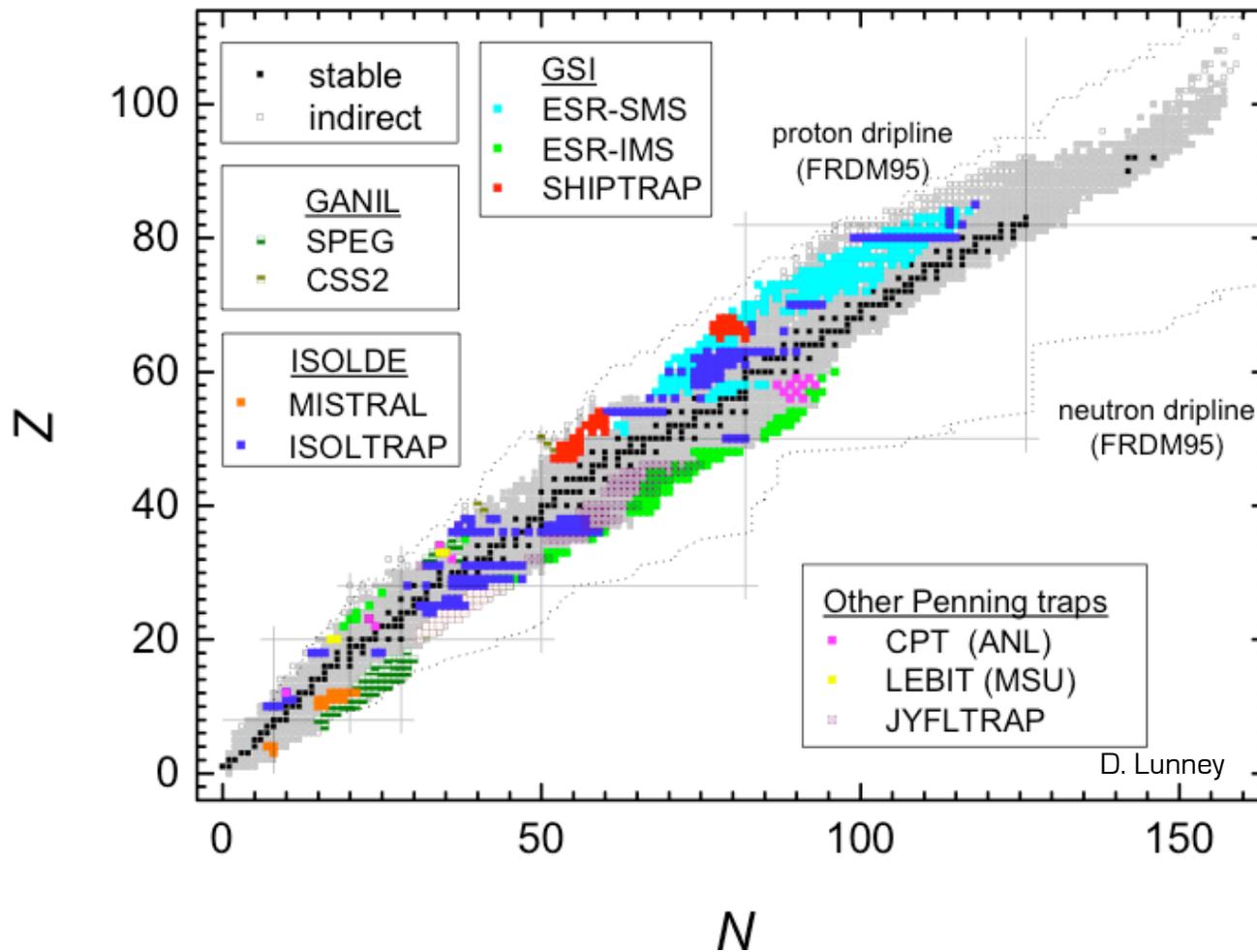
least squares mass adjustment (2003)

- 7773 experimental data (374 rejected)
- primary data: 967 energy and 414 inertia
- plus 887 estimated data
- 1381 equations with 847 parameters
- 2228 ground state masses (and 201 isomers)
- plus 951 estimated values (and 122 isomers)



Audi-Wapstra mass table

# mass measurements



- dramatic increase in number of measurements & their quoted precision

However ... **insufficient manpower** to compile & evaluate all the new masses

also challenging to **rectify systematic uncertainties** between different techniques

# mass evaluation situation

CRISIS

George Audi - Atomic Mass Evaluation leader -  
quit evaluation work [April 2007] ...  
and his colleague A.H. Wapstra  
passed away in 2006

*“Although the responsibility of one evaluation in the AME and its publication should be taken completely by one person, the future of the AME program is the responsibility of each one in our community, not of just one individual”*

*“The future of the AME+Nubase evaluations now depends entirely on the determination of the community involved in atomic masses and its ability to set up a serious project”*

nuclear masses: models, evaluations, disseminations

Ame-fut.txt j April 12, 2007

G. AUDI 4/2007

Just after the publication of the last AME+NUBASE in December 2003, I organized special meetings during conferences to explain the questions raised by the future of the AME. At the same time I have had several discussions with various colleagues. (see newsletter amdc.045 and amdc.04a)

The future of the AME from the user's side would have looked as regularly spaced joint publications of the two evaluations, first in 2008 with myself being responsible, and as co-authors, A.H.Wapstra and N.N. who would learn and help. This person N.N. would then take over the responsibility for the 2013 publication to which I could still contribute. N.N. would then continue and publish, if agreeing with this regularity, a new combined evaluation in 2018 and so on. The importance of having N.N. to work on the evaluation was still increased by the sudden disappearance of A.H.Wapstra in December 2006. Effectively, A.H.Wapstra stopped contributing one year earlier because of health problems.

(It is important to note that a program like the AME should not be conducted by one person alone, because the quality of the work would suffer from no cross-checking of analysis and data handling. In all previous publications of the AME there was no refereeing by the editors, since it was considered that we did our own refereeing through cross-checking of our work.)

This project has always been strongly encouraged by all the persons with whom I discussed.

However, no serious commitment has ever been taken. Even trying as hard as possible, I have not been able to convince the various responsible in our community.

Although the responsibility of one evaluation in the AME and its publication should be taken completely by one person, the future of the AME program is the responsibility of each one in our community, not of just one individual.

Only 20 months remain before the planned next publication in December 2008. In the present situation, it is impossible to conduct a work of the same quality as in 2003. Therefore I am sorry to have to announce that there will not be an Ame2008 as was promised in December 2003, after the publication of Ame2003, and no new evaluations of masses or Nubase are foreseen at present.

As far as I am concerned, in agreement with the authorities in my laboratory, I have stopped the evaluation program and joined an experimental program in our lab, that is not in the field of nuclear masses.

Only in the case where a serious project will be set up, will I return to nuclear masses in order to transmit what I know and help preparing a new evaluation.

The first stage of such project should include an institute INST sending N.N. to Orsay for four years (two years in case of an experienced senior), for him to learn and work on the AME (and NUBASE) and publish the evaluations at the end of this period. Then N.N. would go back to INST to pursue there further evaluations.

The future of the Ame+Nubase evaluations now depends entirely on the determination of the community involved in atomic masses and its ability to set up a serious project.

During the last years, I have received many positive appreciations and encouragements for the evaluation work. My sincere thanks to all those who expressed them. But time is now running so fast that encouragements are no more useful, nor efficient. They must give way to real commitments only.

Therefore, please, direct preferably your comments or your concern to those that you know who have the possibility to set up such a project.

<http://amdc.in2p3.fr/bulletins/Ame-fut.txt>

# mass evaluation crisis

## The AME2003 atomic mass evaluation \*

### (II). Tables, graphs and references

G. Audi<sup>a,§</sup>, A.H. Wapstra<sup>b</sup> and C. Thibault<sup>a</sup>

<sup>a</sup> *Centre de Spectrométrie Nucléaire et de Spectrométrie de Masse, CSNSM, IN2P3-CNRS&UPS, Bâtiment 108, F-91405 Orsay Campus, France*

<sup>b</sup> *National Institute of Nuclear Physics and High-Energy Physics, NIKHEF, PO Box 41882, 1009DB Amsterdam, The Netherlands*

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#### Abstract

This paper is the second part of the new evaluation of atomic masses AME2003. From the results of a least-squares calculation described in Part I for all accepted experimental data, we derive here tables and graphs to replace those of 1993. The first table lists atomic masses. It is

no **2008 update** of the AME2003 evaluation as planned ...

serious new evaluation program needed !

2 - 4 years training required for new AME leader [Audi will assist ...]

crucial: involve **many institutions** **WORLDWIDE** to contribute to mass evaluations

nuclear masses: models, evaluations, disseminations michael smith ornl

# mass evaluation: new european proposal

- proposal to European Nuclear Science & its Applications Research [ENSAR ]

## NJRA-10 task 4: AAME (Advanced Atomic Mass Evaluation)

*Task Leader Y. Litvinov (GSI)*

The nuclear binding energy, through the mass, is one of the most basic properties of a nuclide. In addition to fundamental information on nuclear structure, the mass dictates the amount of energy available for a reaction or decay, thus having decisive influence in wide variety of scientific domains besides nuclear physics such as nuclear astrophysics and energy generation. Accurate data on atomic masses are important in atomic physics, chemistry, metrology, applied mass spectroscopy etc.. The success of radioactive beam facilities mainly in Europe (and associated experiments) has lead to a notable increase in quantity (and quality) of atomic mass data in hitherto inaccessible regions of the nuclear chart. It is proposed to collect experimental data (masses, Q-values, excitation energies,

Yuri Litvinov [GSI] - Principal Investigator

network of 9 experimental groups [in Germany, France, Finland, Switzerland, Sweden, & Great Britain]

involvement of a number of theorists as well

**unique aspects:** for the first time, couple centers with active mass measurement work to form an evaluation *network*

**other features:** website with interactive tools, database with evaluated & theoretical masses, bulletins, virtual journal, annual working group meetings

**deliverable:** new mass evaluation by **2012**

nuclear masses: models, evaluations, disseminations michael smith orn!

# mass evaluation: new european proposal

- proposal to European Nuclear Science & its Applications Research [ENSAR ]

## NJRA-10 task 4: AAME (Advanced Atomic Mass Evaluation)

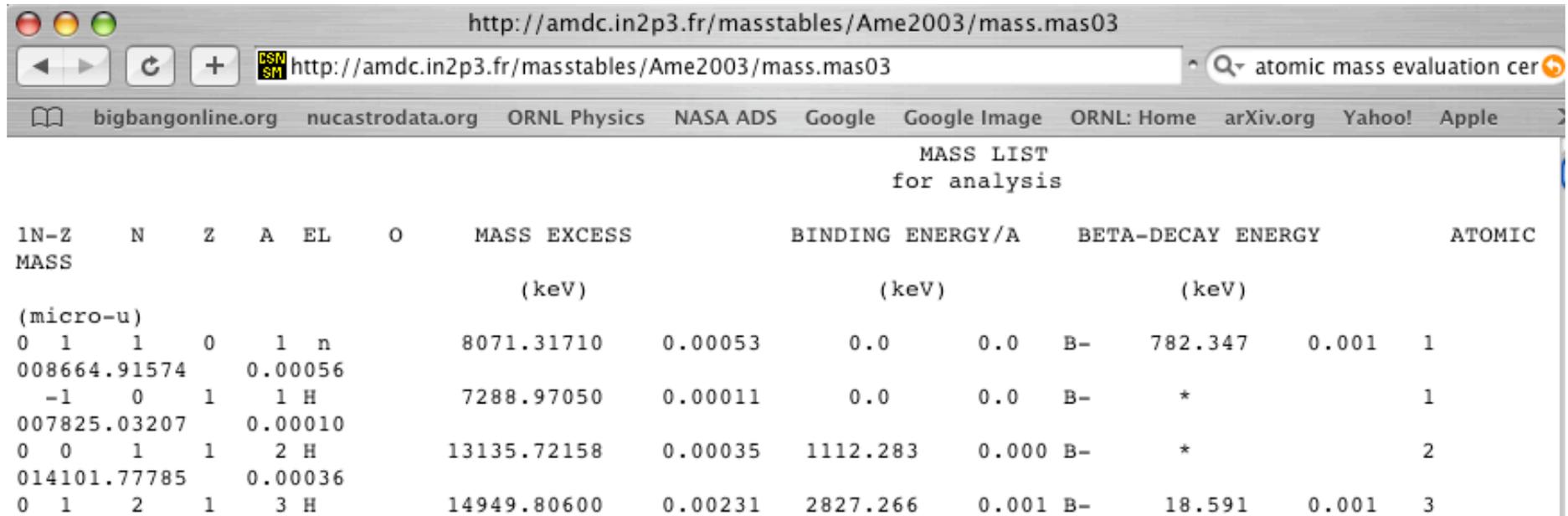
*Task Leader Y. Litvinov (GSI)*

The nuclear binding energy, through the mass, is one of the most basic properties of a nuclide. In addition to fundamental information on nuclear structure, the mass dictates the amount of energy available for a reaction or decay, thus having decisive influence in wide variety of scientific domains besides nuclear physics such as nuclear astrophysics and energy generation. Accurate data on atomic masses are important in atomic physics, chemistry, metrology, applied mass spectroscopy etc.. The success of radioactive beam facilities mainly in Europe (and associated experiments) has lead to a notable increase in quantity (and quality) of atomic mass data in hitherto inaccessible regions of the nuclear chart. It is proposed to collect experimental data (masses, Q-values, excitation energies,

- rejected as stand-alone Joint Research Activity [JRA] by steering committee
- revised to be combined with Nuclear Theory JRA November 2007
- budget cuts led to mass evaluations being *cut out* December 2007
- ***future of this European effort is uncertain*** [funding by another agency?]

***...still a crisis situation !***

# dissemination of masses



MASS LIST  
for analysis

1N-Z	N	Z	A	EL	O	MASS EXCESS (keV)	BINDING ENERGY/A (keV)	BETA-DECAY ENERGY (keV)	ATOMIC				
0 1	1	0	1	n		8071.31710	0.00053	0.0	0.0	B-	782.347	0.001	1
008664.91574													
-1	0	1	1	H		7288.97050	0.00011	0.0	0.0	B-	*		1
007825.03207													
0 0	1	1	2	H		13135.72158	0.00035	1112.283	0.000	B-	*		2
014101.77785													
0 1	2	1	3	H		14949.80600	0.00231	2827.266	0.001	B-	18.591	0.001	3

- primary means of mass dissemination: **text tables** [flat files]
- **primitive**: no plotting, no searching, no comparing theory & evaluated masses
- these & other manipulation of data files is left to *advanced users* who download the flat file and use their own programs [PC-Nucleus, IDL ... ]
- result: majority of users of nuclear masses have **never browsed, compared, or done detailed investigations** of the data files

# dissemination of masses

- tremendous effort goes into new mass measurements, theoretical mass models, and mass evaluations
- significant return on this investment can be realized by **sophisticated dissemination** of this information
- would be ideal to create an **online system** focused on nuclear masses that enables researchers to

*upload a new mass model and visualize mass excess,  $S_n$ ,  $S_p$ ,  $S_\alpha$  ...*

*upload new experimental masses and compare to latest evaluation*

*compare theoretical mass models to latest evaluation & each other*

*visualize theoretical & evaluated masses - separately and differences*

*comment on data sets [form an online community]*

*manipulate, browse, & search data sets*

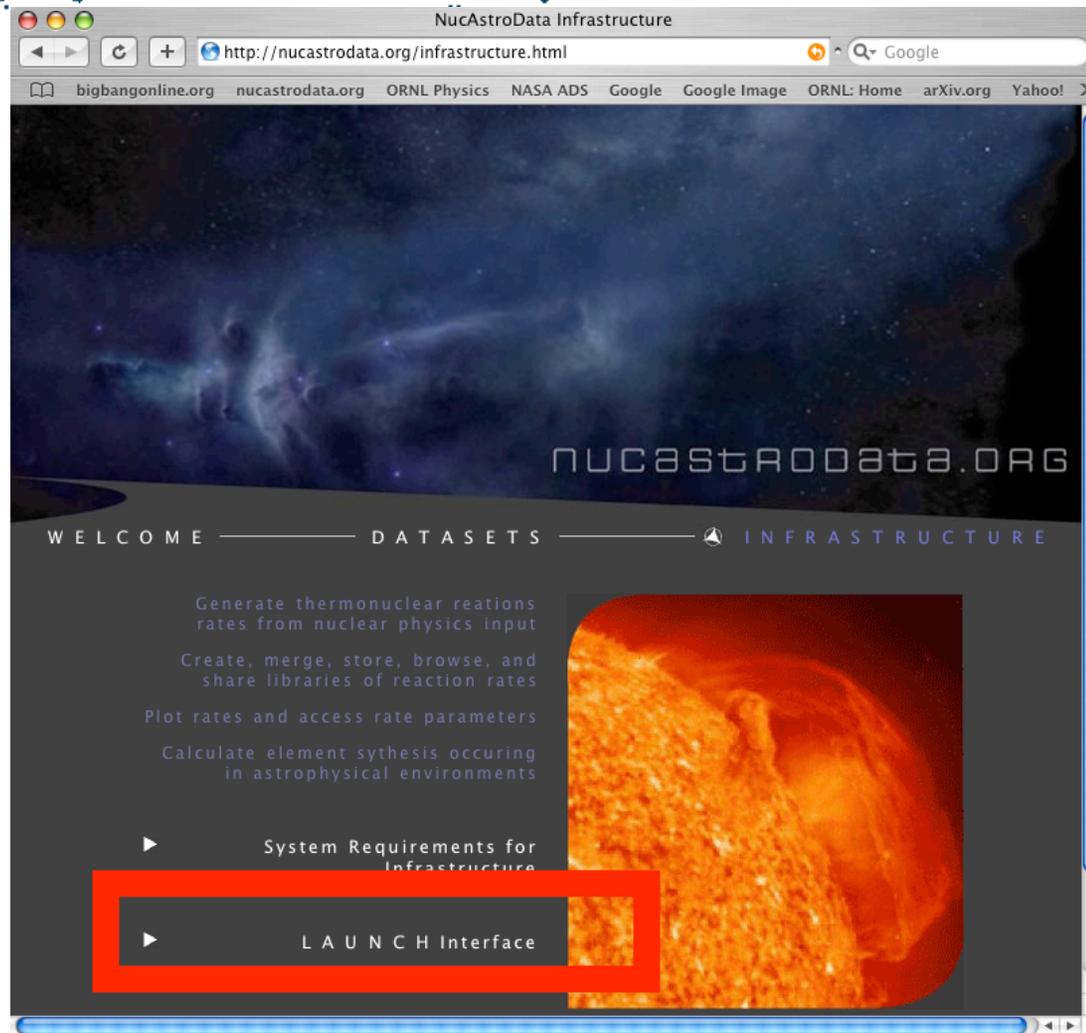
*bibliographic links for evaluations, experiments & facilities, mass models ...*

- advances in computers and networking make this a very reasonable goal

# dissemination of masses at nucastrodata.org

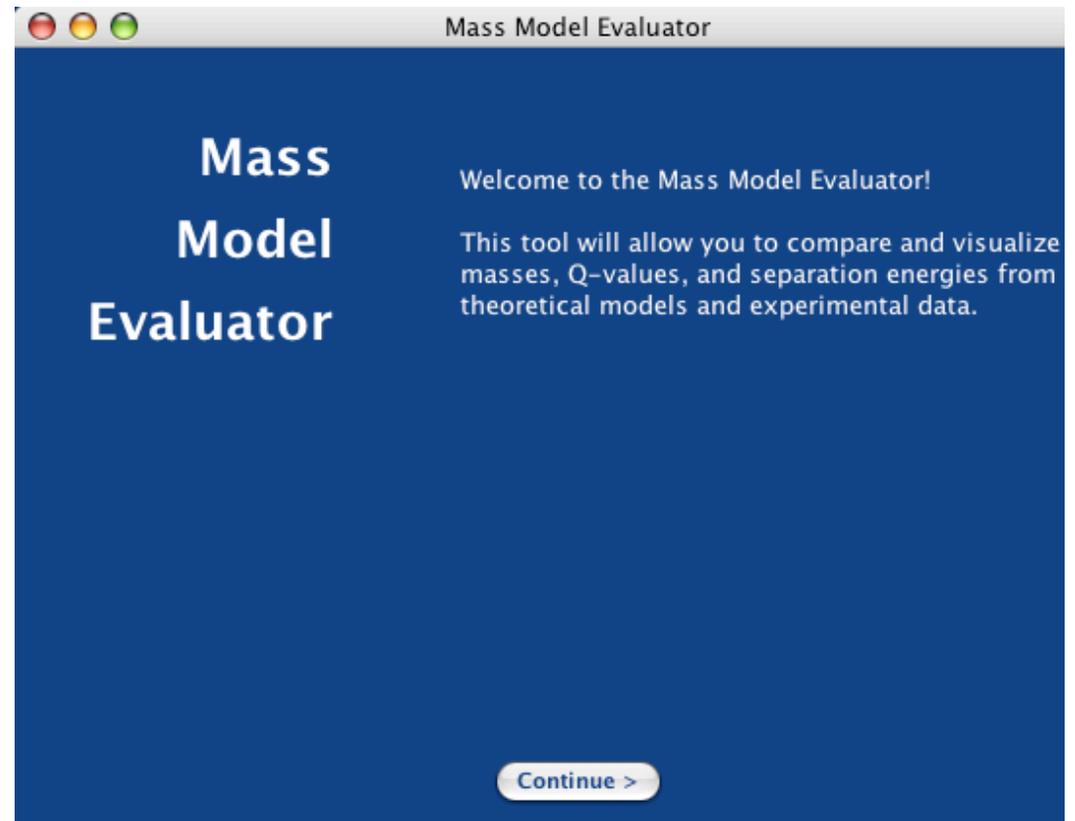
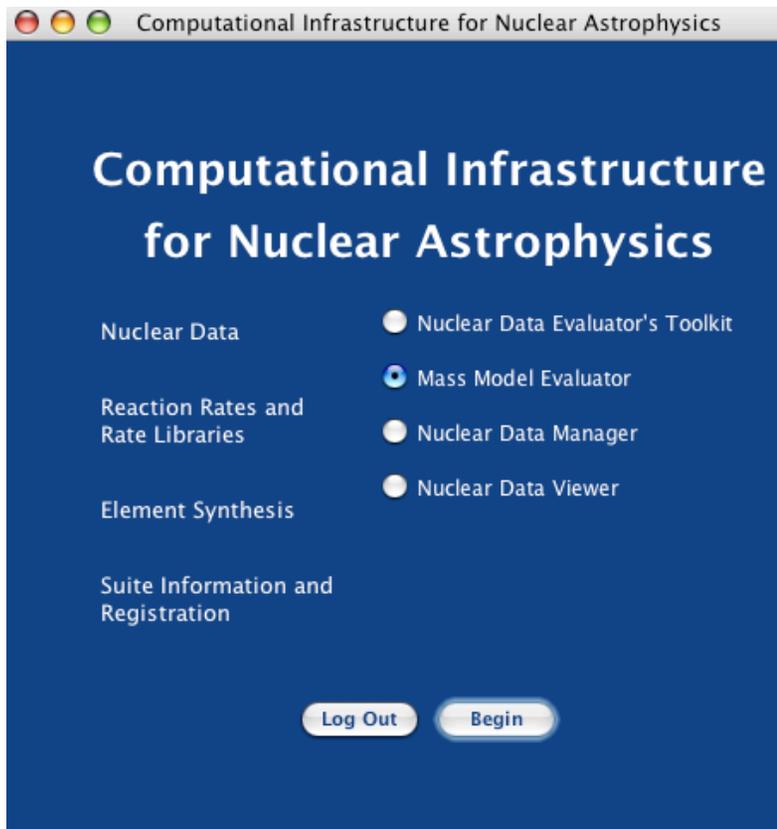
- we have a *prototype* of such an online system - within the **Computational Infrastructure for Nuclear Astrophysics**, online at **nucastrodata.org**
  - *upload a new mass model and visualize mass excess,  $S_n$ ,  $S_p$ ,  $S_\alpha$  ...*
    - upload new experimental masses and compare to latest evaluation*
  - *compare theoretical mass models to latest evaluation & each other*
  - *visualize theoretical & evaluated masses - separately and differences*
    - comment on data sets [form an online community]*
    - manipulate, browse, & search data sets*
    - bibliographic links for evaluations, experiments & facilities, mass models ...*
- system is **free** for anyone to use - just need a computer with JAVA [client application] and an internet connection [to communicate with our server]

# dissemination of masses at nucastrodata.org



- download a java application for your laptop/desktop/workstation , from <http://nucastrodata.org/infrastructure>

# dissemination of masses at nucastrodata.org



- launch the application, log in, and select “Mass Model Evaluator”

nuclear masses: models, evaluations, disseminations michael smith orn

# dissemination of masses at nucaastrodata.org

Mass Model Evaluator | Select Theoretical Mass Model Step 2 of 4

Select a THEORETICAL MASS MODEL from the dropdown menu or upload a theoretical mass model below :

select theoretical mass model KTUY05

upload theoretical mass model

Notes for this mass model are shown below :

KTUY05 mass formula  
by H. Koura, T.Tachibana, M. Uno and M. Yamada  
Progr. Theor. Phys., 113 (2005) pp.305

This mass formula is composed of a gross term, an even-odd term  
and a shell term.

The even-odd term represents a correction of nuclear...

models:  
FRDM95  
KTUY05  
HFB8  
HFB14  
ETSFI 2  
WB03  
Duflo-  
Zuker

- choose a theoretical mass model

# dissemination of masses at nucastrodata.org

Mass Model Evaluator | Select Theoretical Mass Model Step 2 of 4

Select a THEORETICAL MASS MODEL from the dropdown menu or upload a theoretical mass model below :

select theoretical mass model KTUY05

upload theoretical mass model ny\_mass\_model.rtf Browse...

[Help on File Format](#)

Enter notes in the area below :

my own mass model

[< Back](#) [Continue >](#)

- ... or upload your own mass model

# dissemination of masses at nucastrodata.org

The screenshot shows a web browser window titled "Mass Model Evaluator". The page header indicates "Mass Model Evaluator | Select Reference Mass Model" and "Step 3 of 4". The main instruction is "Select a REFERENCE MASS MODEL from the dropdown menu or upload a reference mass model below :". There are two radio buttons: "select reference mass model" (which is selected) and "upload reference mass model". The "select reference mass model" option is associated with a dropdown menu currently showing "AMDC (standard)", which is highlighted with a red box. The "upload reference mass model" option is associated with a text input field and a "Browse..." button. Below these options is a "Help on File Format" button. A section titled "Notes for this mass model are shown below :" contains a text box with the following text: "The AME2003 atomic mass evaluation (II). Tables, graphs, and references. G. Audi, A.H. Wapstra, and C. Thibault. Nuclear Physics A729, 337 (2003).". At the bottom of the page are two buttons: "< Back" and "Continue >".

- choose a second theoretical model or the AME2003 evaluated data set

# dissemination of masses at nucastrodata.org

Mass Model Evaluator | Mass Model Results Step 4 of 4

Theoretical Mass Model : KTUY05 Reference Mass Model : AMDC

Click the *Open Mass Differences/RMS Plotter (1-D)* button to make 1-D plots of mass excess differences and the RMS values of mass excess differences.

[Open Mass Differences/RMS Plotter \(1-D\)](#)

Click the *Open Interactive Nuclide Chart (2-D)* button to view 2-D plots of  $n$ ,  $2n$ ,  $p$ ,  $2p$ , and alpha separation energies and  $(\alpha, n)$ ,  $(\alpha, p)$ , and  $(p, n)$   $Q$ -values for theoretical and reference mass models, as well as the difference and absolute difference of these values.

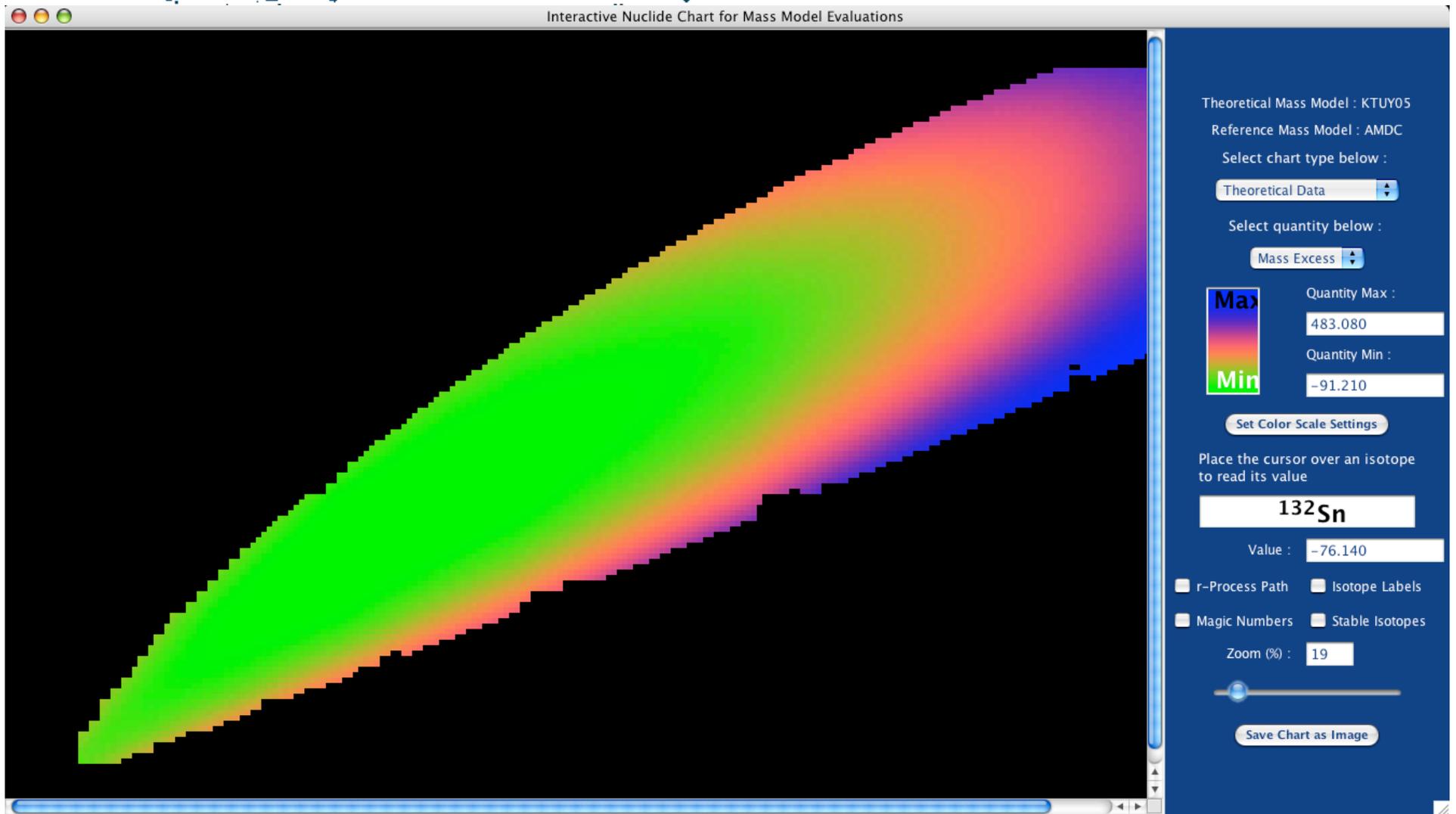
[Open Interactive Nuclide Chart \(2-D\)](#)

r-Process path from  
**NUCLEAR PROPERTIES FOR ASTROPHYSICAL AND RADIOACTIVE-ION-BEAM APPLICATIONS**  
P. MÖLLER, J. R. NIX, K. -L. KRATZ, Atomic Data Nuclear Data Tables 66 (1997) 131.  
using FRDM95 model.

[< Back](#) [Close Mass Model Evaluator](#) [Nuclear Data Evaluator's Toolkit](#)

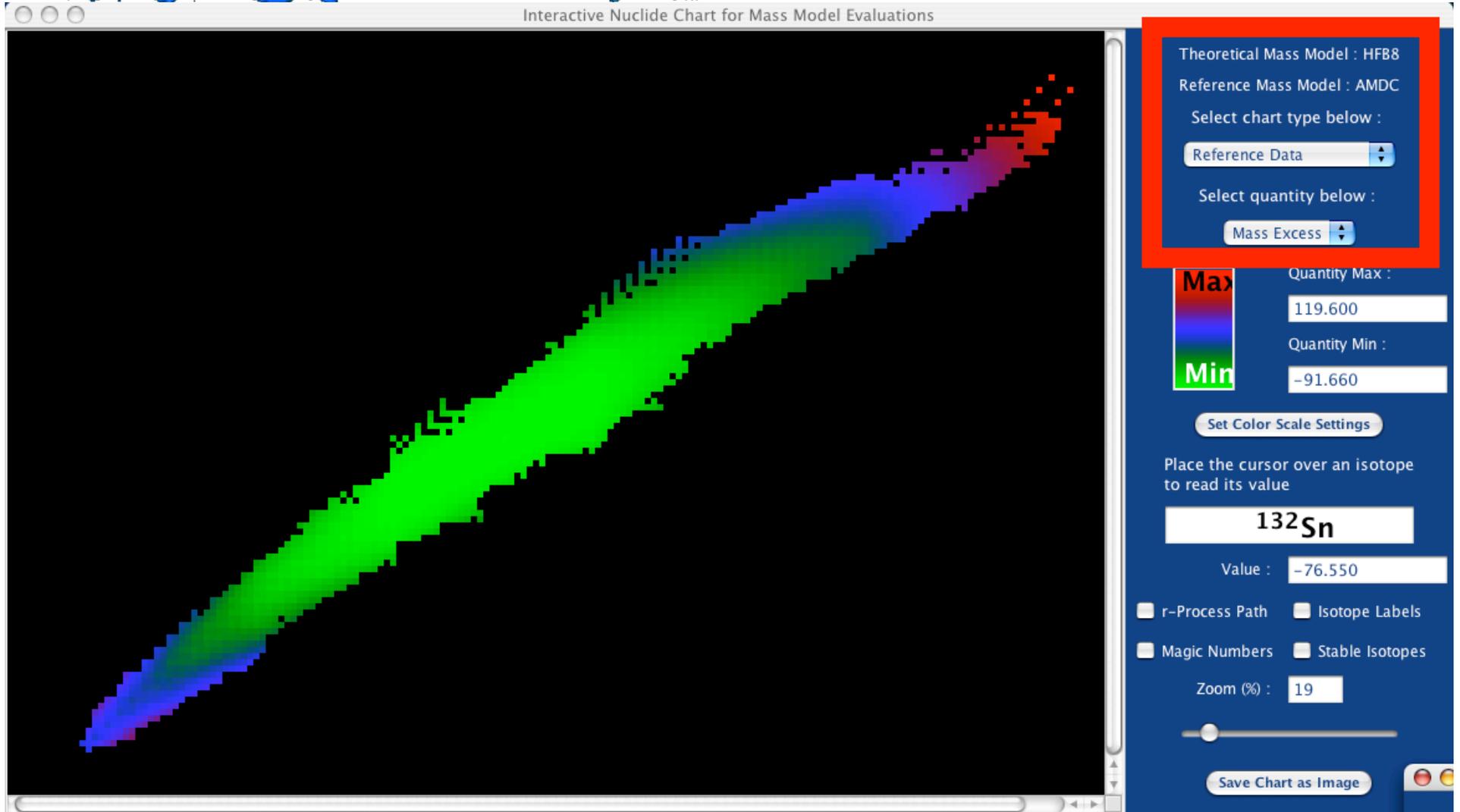
- choose 1-D or 2-D plots

# dissemination of masses at nucastrodata.org



- visualize mass excess of the KTUY05 mass model

# dissemination of masses at nucastrodata.org



- visualize mass excess of the AME2003 evaluated masses

# dissemination of masses at nucaastrodata.org

Mass Model Nuclide Chart Color Scale Settings

Select type of color scale : Continuous

With this tool, you can set the floor and ceiling of the mass model nuclide chart color scale and select a new color scheme for the Mass Model Evaluator by using the sliders below.

Value max : 119.600

Value min : -91.660

Map values outside of range to max/min color

Show only values within this range

Choose a color scheme : Purple Haze

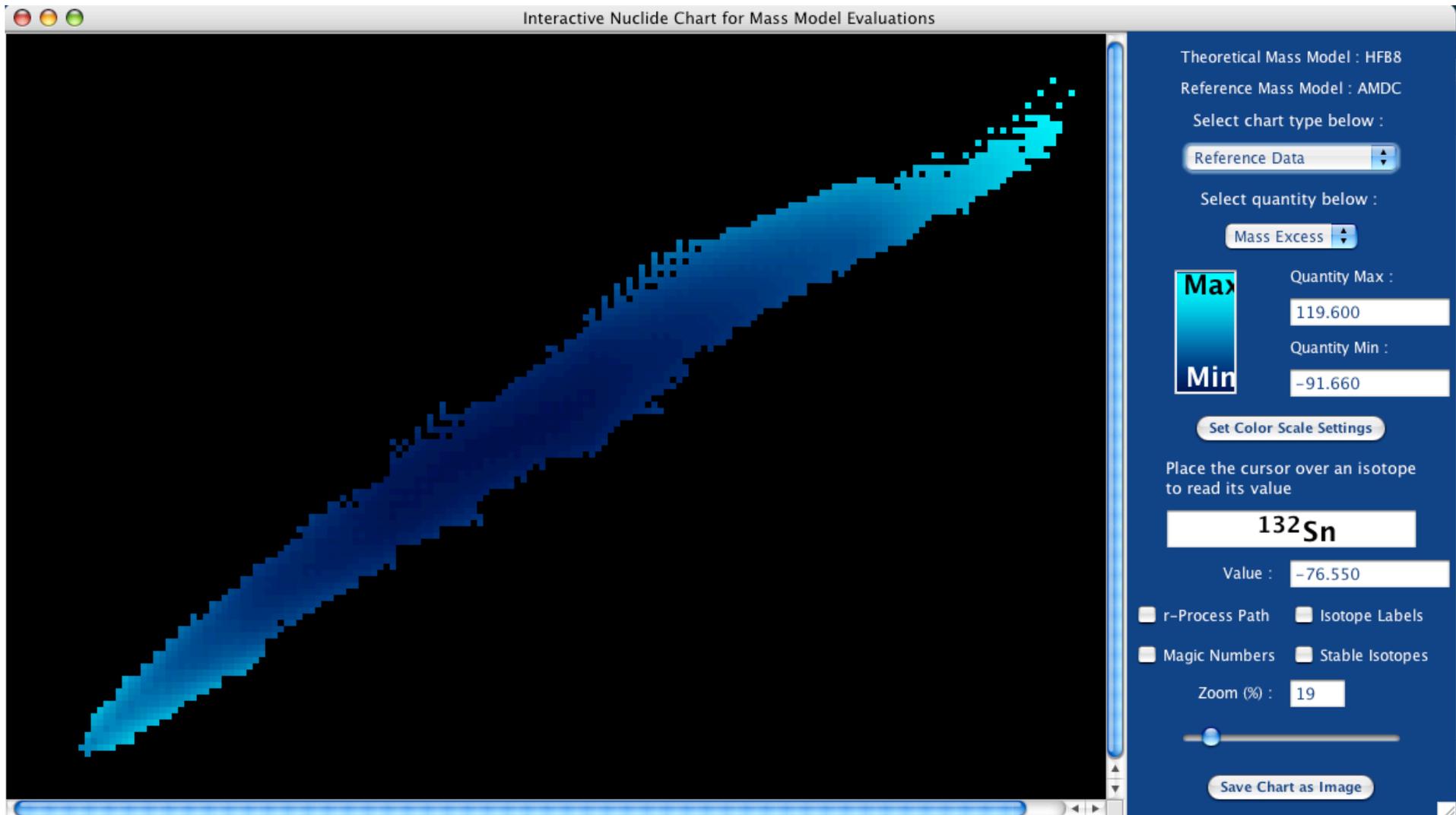
Max  
Min

Color	Position	Amount
Red	0.0	0.0
Green	1.0	0.58
Blue	1.0	0.84

Default Settings Apply Settings Enter Max/Min Range Help on This Interface

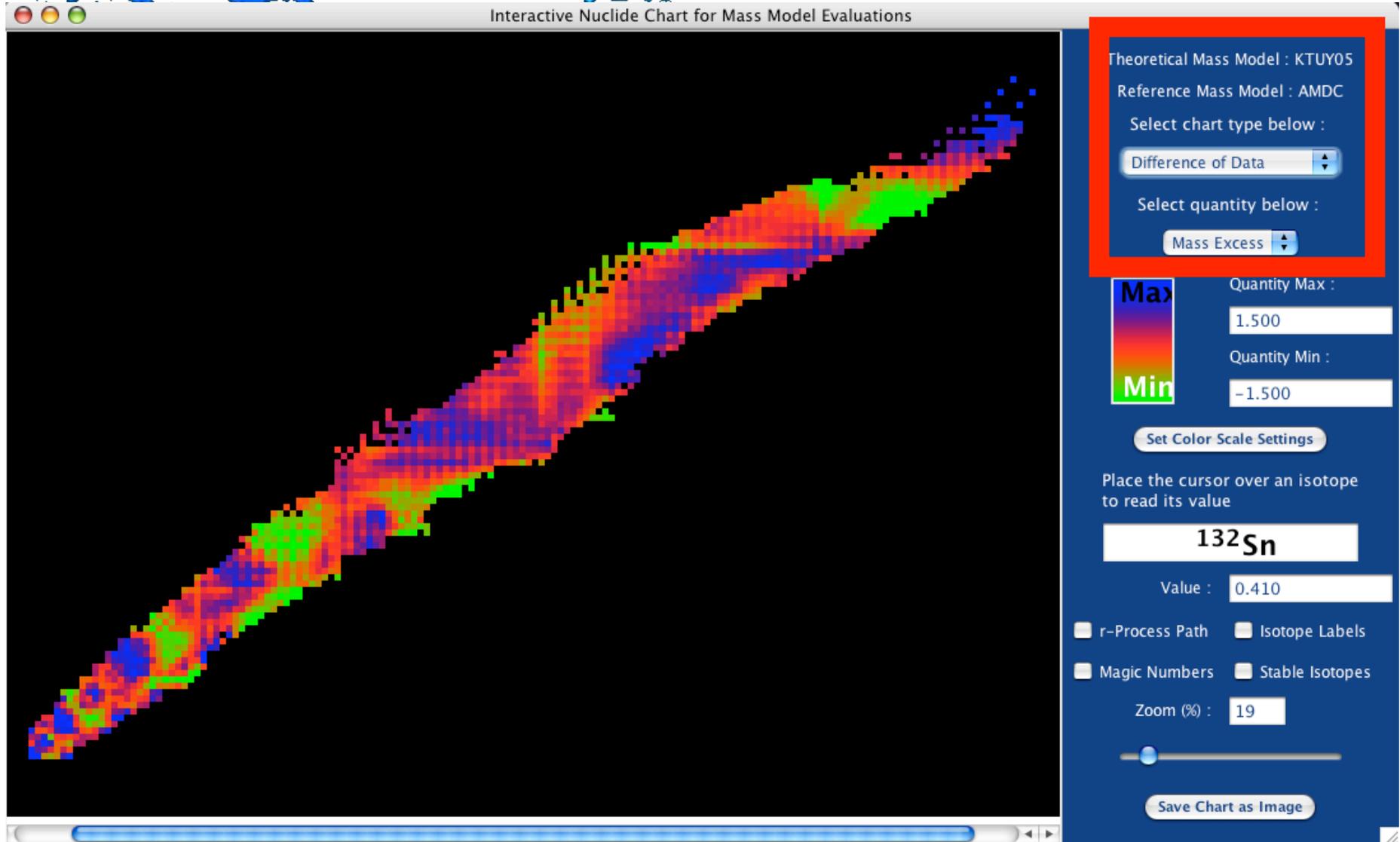
- customize the color mapping ...

# dissemination of masses at nucastrodata.org



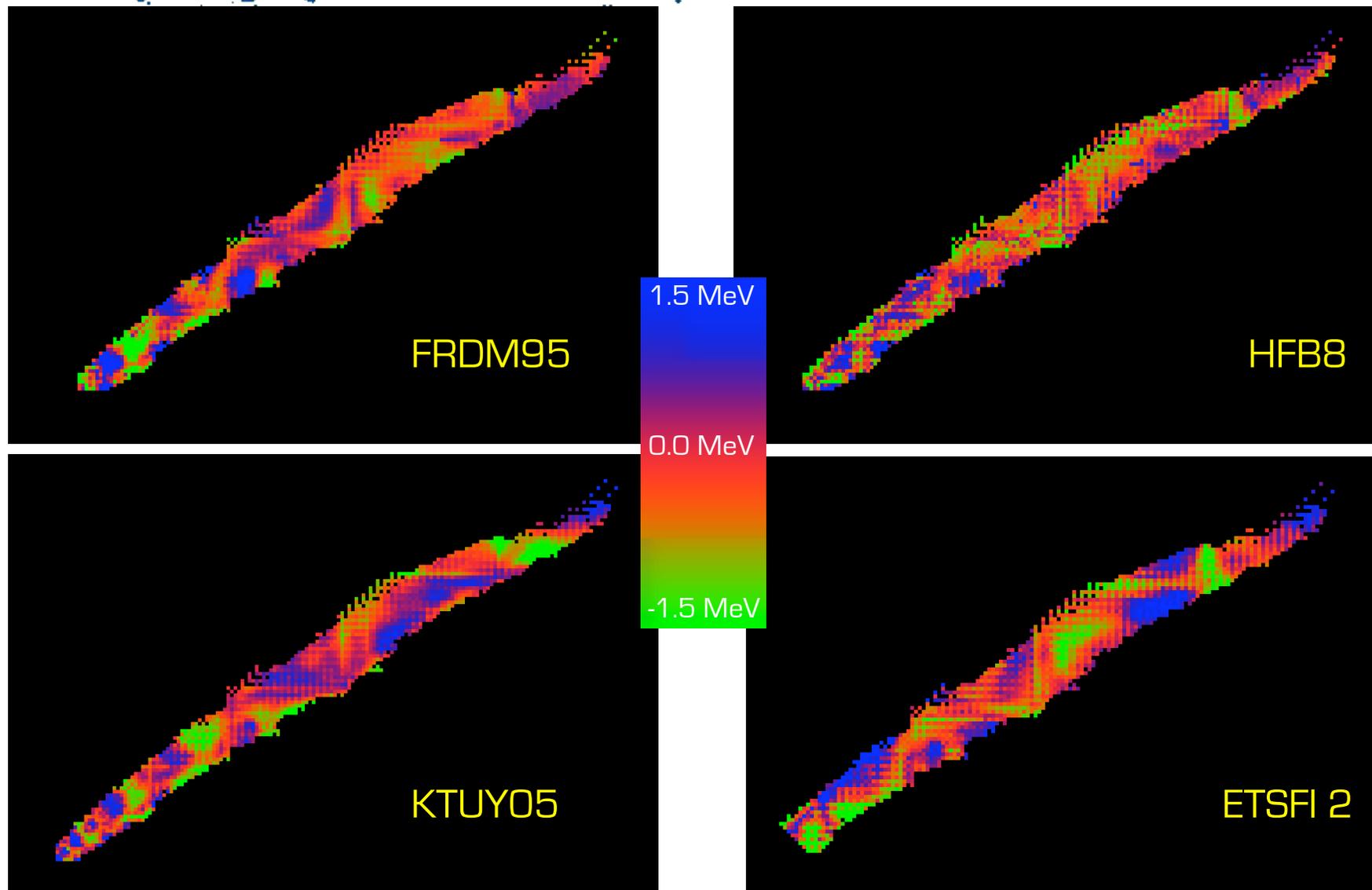
- visualize a new nuclide chart with AME2003 mass excesses

# dissemination of masses at nucastrodata.org



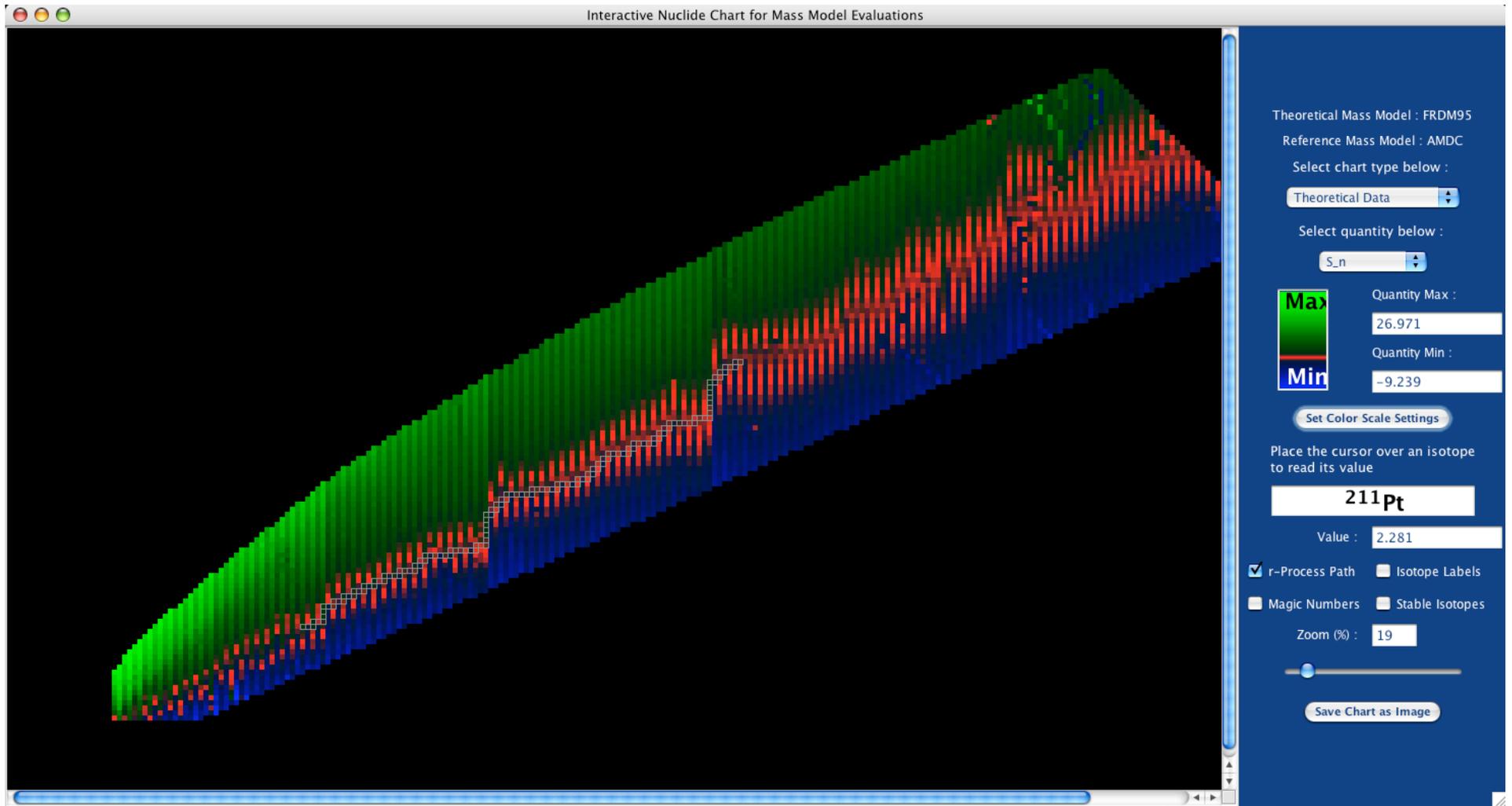
- show mass differences between KTUY05 and AME2003 masses

# dissemination of masses at [nucastrodata.org](http://nucastrodata.org)



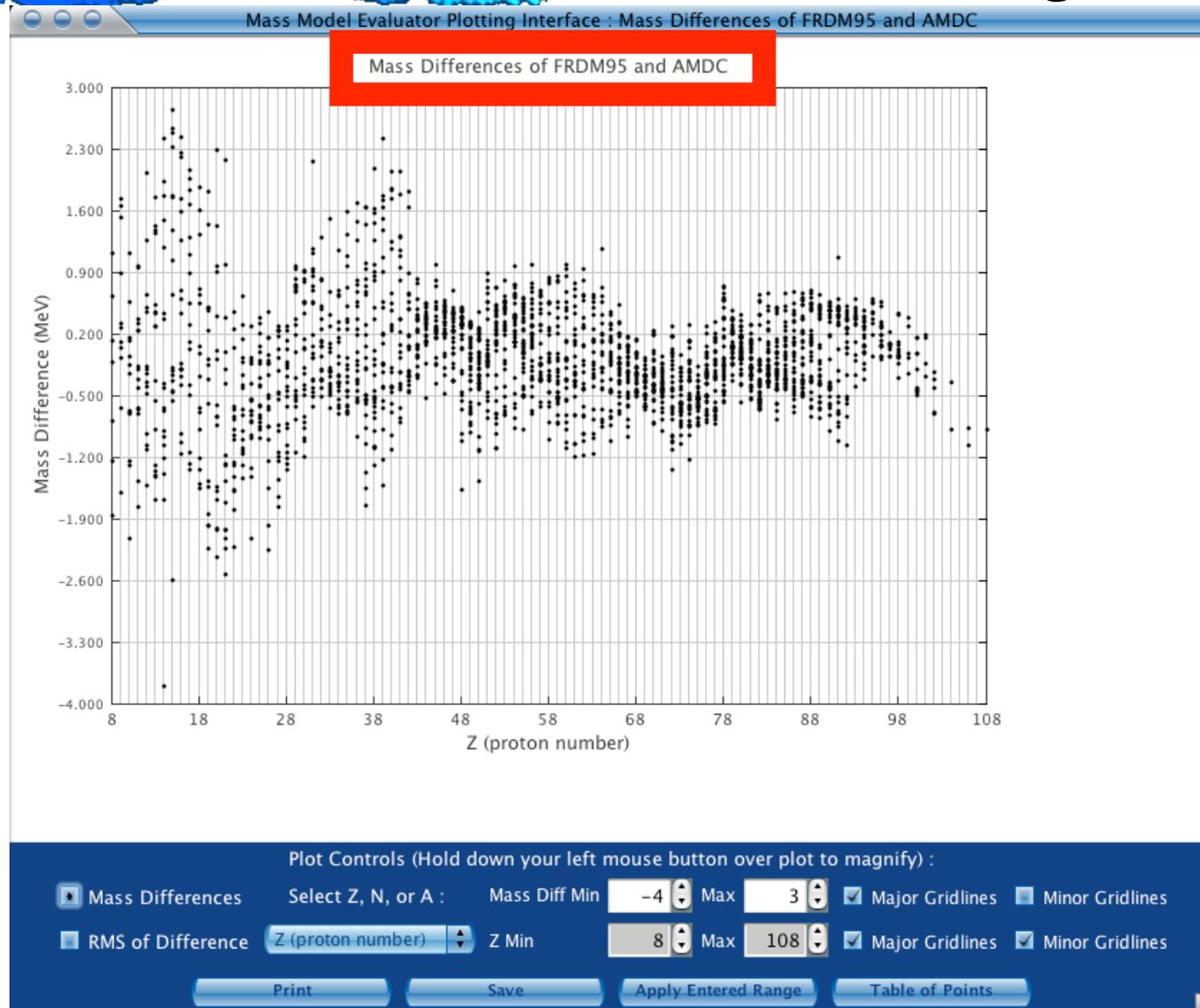
- quickly compare mass differences between models & AME2003 masses

# dissemination of masses at nucastrodata.org



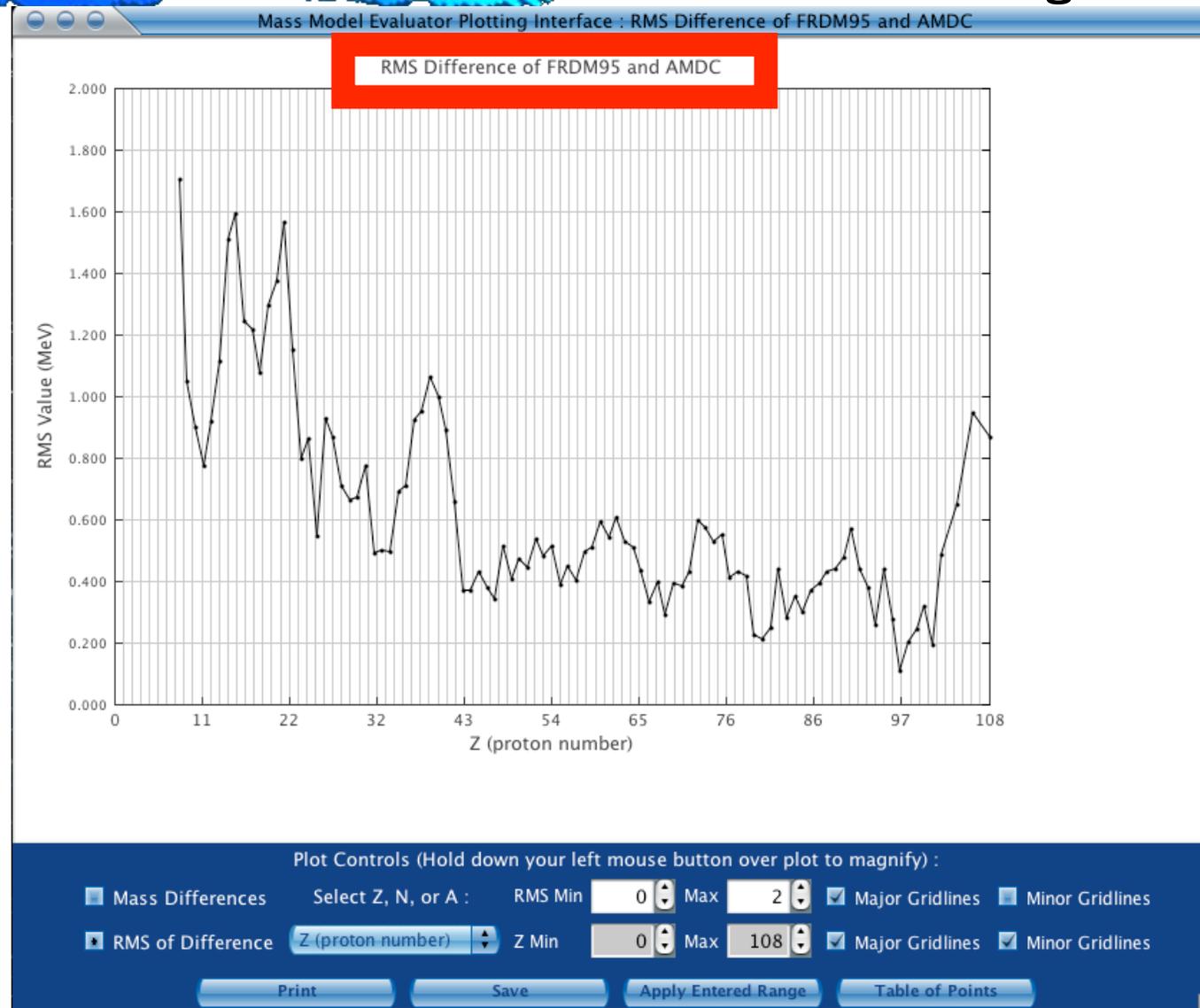
- visualize neutron separation energies of the FRDM95 theoretical mass model with an r-process path overlaid [can also show  $S_{2n}$ ,  $S_p$ ,  $S_{2p}$ ,  $S_\alpha$ ,  $Q$  values...]

# dissemination of masses at nucastrodata.org



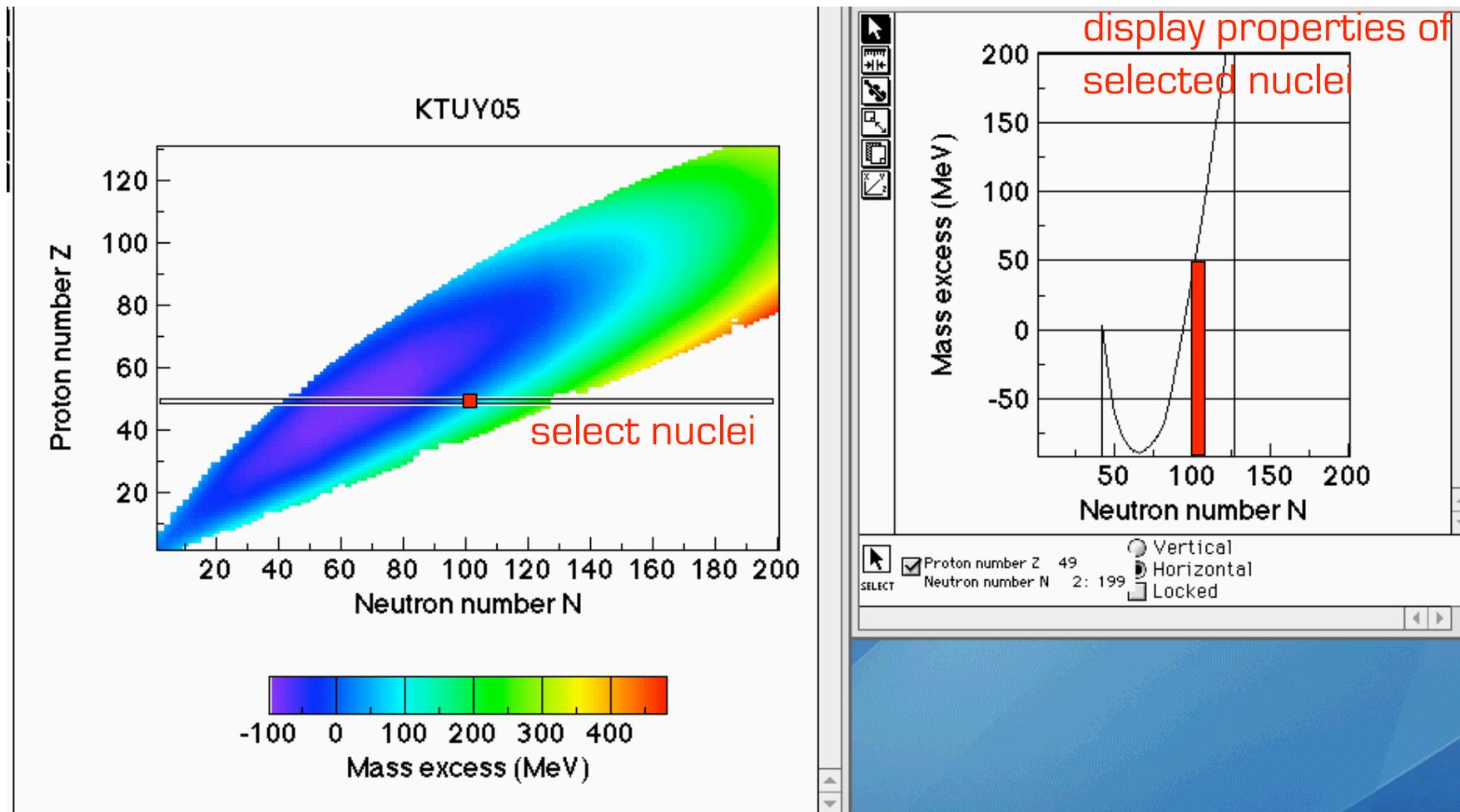
- show full complement of 1-D plots comparing theory & evaluated masses

# dissemination of masses at nucastrodata.org



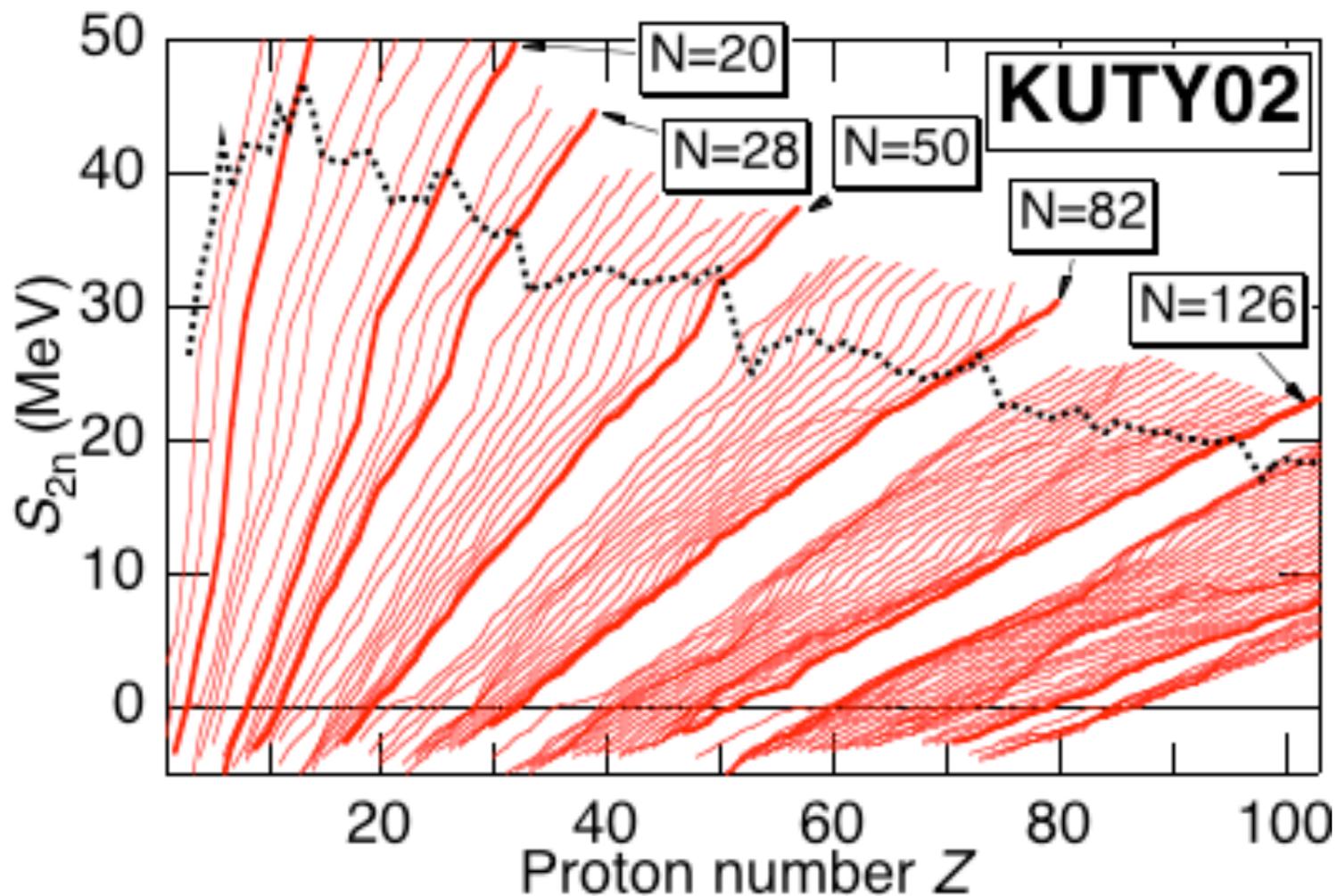
- show full complement of 1-D plots comparing theory & evaluated masses

# future plans for mass dissemination



- develop tools for mass model manipulations [with H. Koura, JAEA]

## future plans for mass dissemination



- develop tools for mass model manipulations [with H. Koura, JAEA]

# future plans for mass dissemination

- upload additional theoretical mass models
- develop tool for uploading experimental masses
- enable commenting on different mass models
- improved management of mass data files
- move these tools into a dedicated, separate site for mass information
- **utilize these visualization / processing / data management tools for software support of some NEW future mass evaluation effort**

# opportunity for new effort in nuclear masses

- more, and more precise measurements with techniques using very different systematics
- more sophisticated mass models with better and better agreement with evaluated masses

- a **crisis** in mass evaluations

*“ ... the future of the AME program is the responsibility of each one in our community ”*

*G. Audi, April 2007*

- a continued **limited, primitive dissemination** of evaluated, experimental, and theoretical masses
- this suggests an **OPPORTUNITY** for new evaluation & dissemination efforts

# opportunity for new effort in nuclear masses

- an excellent overlap with activities / interests of JUSTIPEN members & other nuclear scientists in the U.S. and Japan

RIKEN - mass measurements with exotic beams

JAEA - nuclear mass models, nuclear data compilation, evaluation, & dissemination

Argonne National Lab - mass measurements, nuclear data evaluations

Michigan State Univ. - mass measurements with exotic beams

Oak Ridge National Lab - data processing / dissemination software

*and many many more ...*

- are JUSTIPEN **members** interested in a new effort ? [why sit this out ?]
- is JUSTIPEN as an **organization** interested in joining / promoting / sponsoring / *taking initiative & leadership* for *a new effort in nuclear masses* ?
- **action is needed soon** as a new mass evaluation takes years to complete and AME2003 is already 5 years out of date

# summary

- nuclear masses absolutely crucial for studies in nuclear structure, nuclear reactions, nuclear astrophysics ...
- dramatic increase in number of mass measurements & their quoted precision at **exotic** & stable beam facilities in Europe, U.S., Japan ...
- mass models are getting more sophisticated and have ever-increasing agreement with evaluated masses

## However ...

- a **CRISIS** in evaluations of masses - will there be an update of the AME2003 Atomic Mass Evaluation ?
- a continued **limited, primitive dissemination** of evaluated, experimental, and theoretical masses
- this represents an **opportunity** for new efforts – with an excellent overlap with activities / interests of JUSTIPEN members