Nuclear level densities for SBSS

-- and can RIA help ?

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LANCE-3

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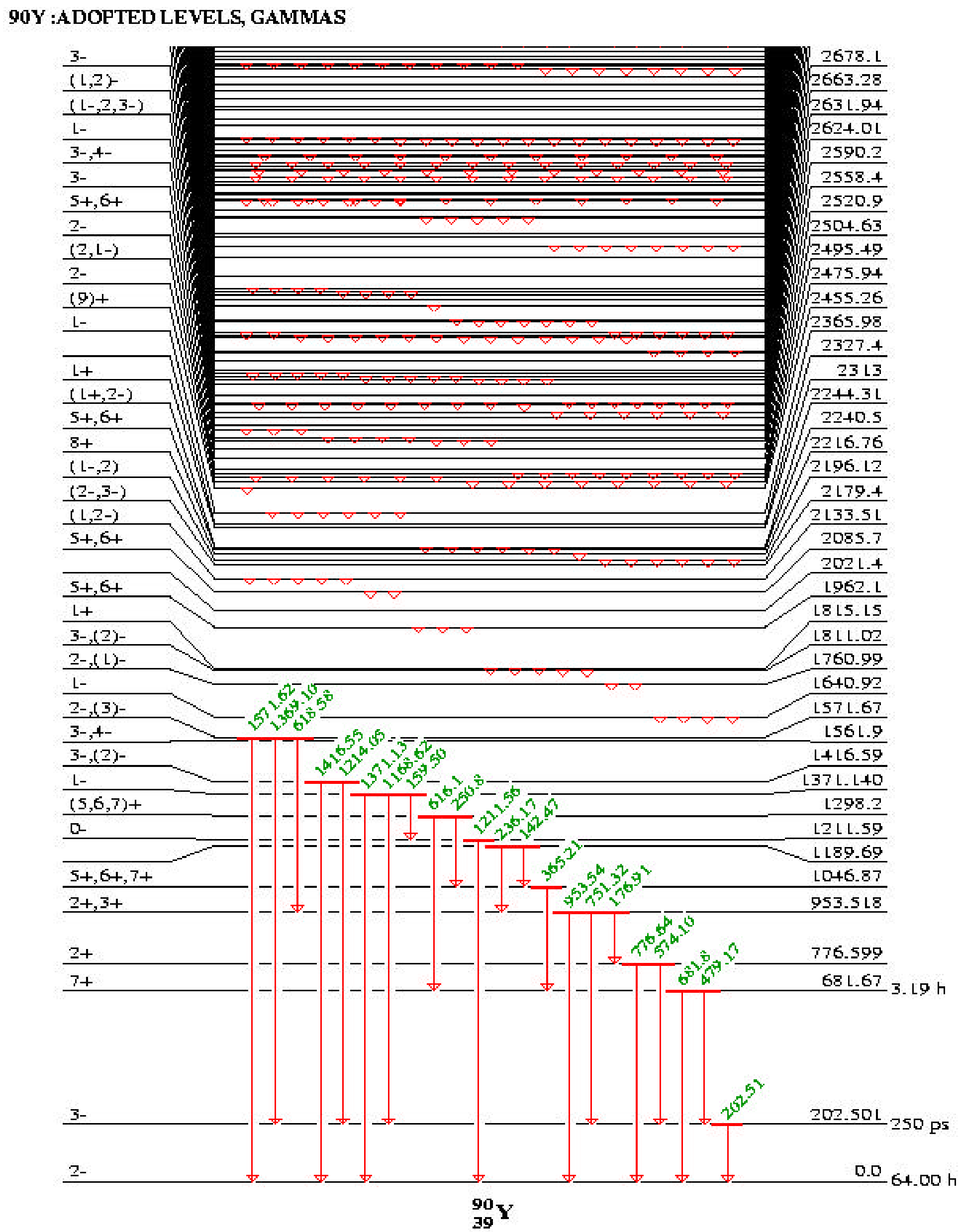
Outline -- Nuclear level densities

- What are they?
- Why are they needed?
- How are they measured?
- Present state of data
- Outstanding problems
- How can RIA address these problems?

Nuclear levels in a “typical” nucleus:

There sure are lots of levels!!



The nuclear level density is
the number of levels
per unit excitation energy
at excitation energy U

$\rho\ (U)$

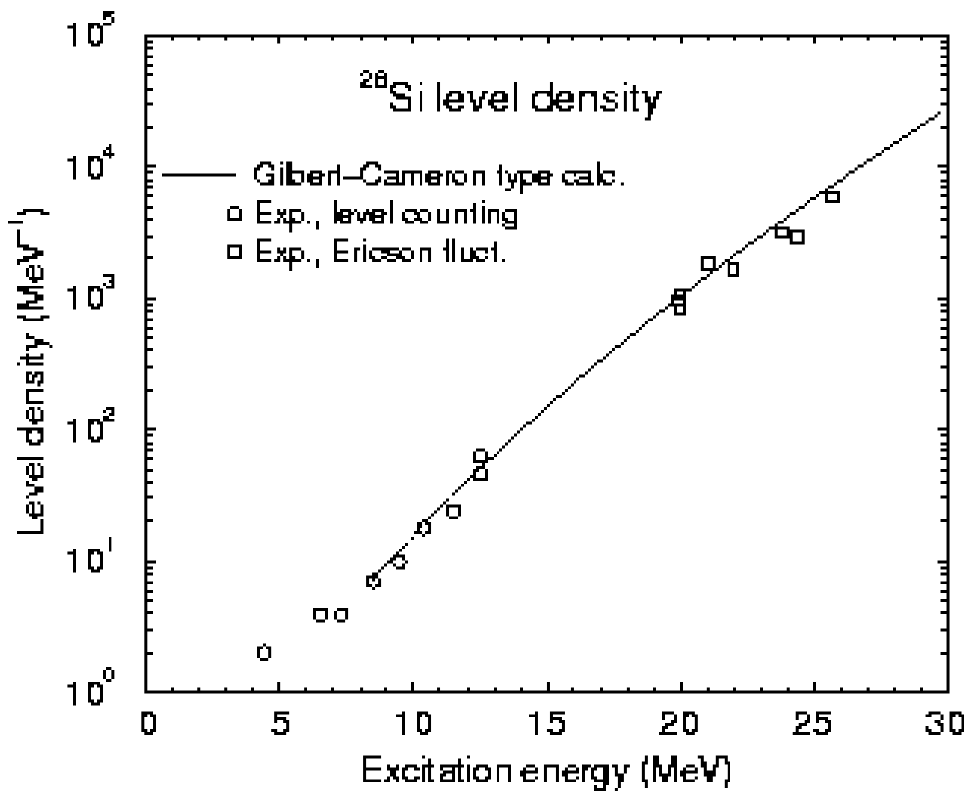
or, better,

$\rho\ (U,J,\pi)$

or, even better

$\rho\ (U,J,\pi,T)$

Level densities for silicon -- an example

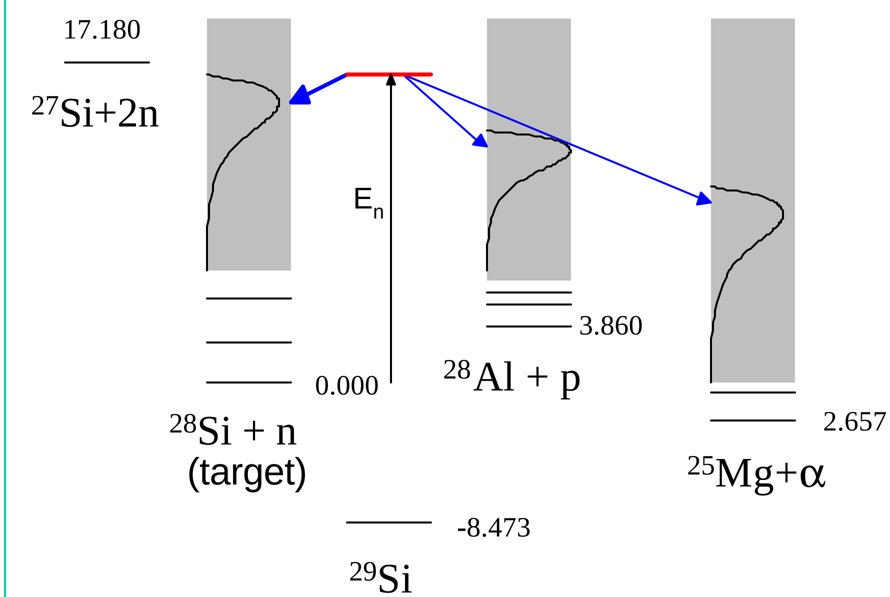


Why are nuclear level densities interesting?

- Basic quantity of many-body quantum-mechanical system
  - Transition from ordered levels to disordered Fermi gas
  - Possibility of observing phase change
- Applications
  - Calculations of cross sections -- esp. for reactions that cannot be measured -- astrophysics, weapons
  - Calculations of radiation effects -- e.g. recoiling nuclei in semiconductors irradiated with neutrons

Why are level densities needed ?

Answer: to calculate cross sections in order to
(1) provide data that cannot be measured
(2) resolve discrepancies in existing data



note: competing channels !

$$\sigma_{c,c'} = \sigma_{c,cn} \bullet \frac{T_{c'}}{\Sigma\, T_{c''}}$$

Level density

$$T_{c'} = \Sigma\, T_{c'}(E_n^*) + \int T_{c'}(E_n^*)\, \rho(\varepsilon)\, d\varepsilon$$

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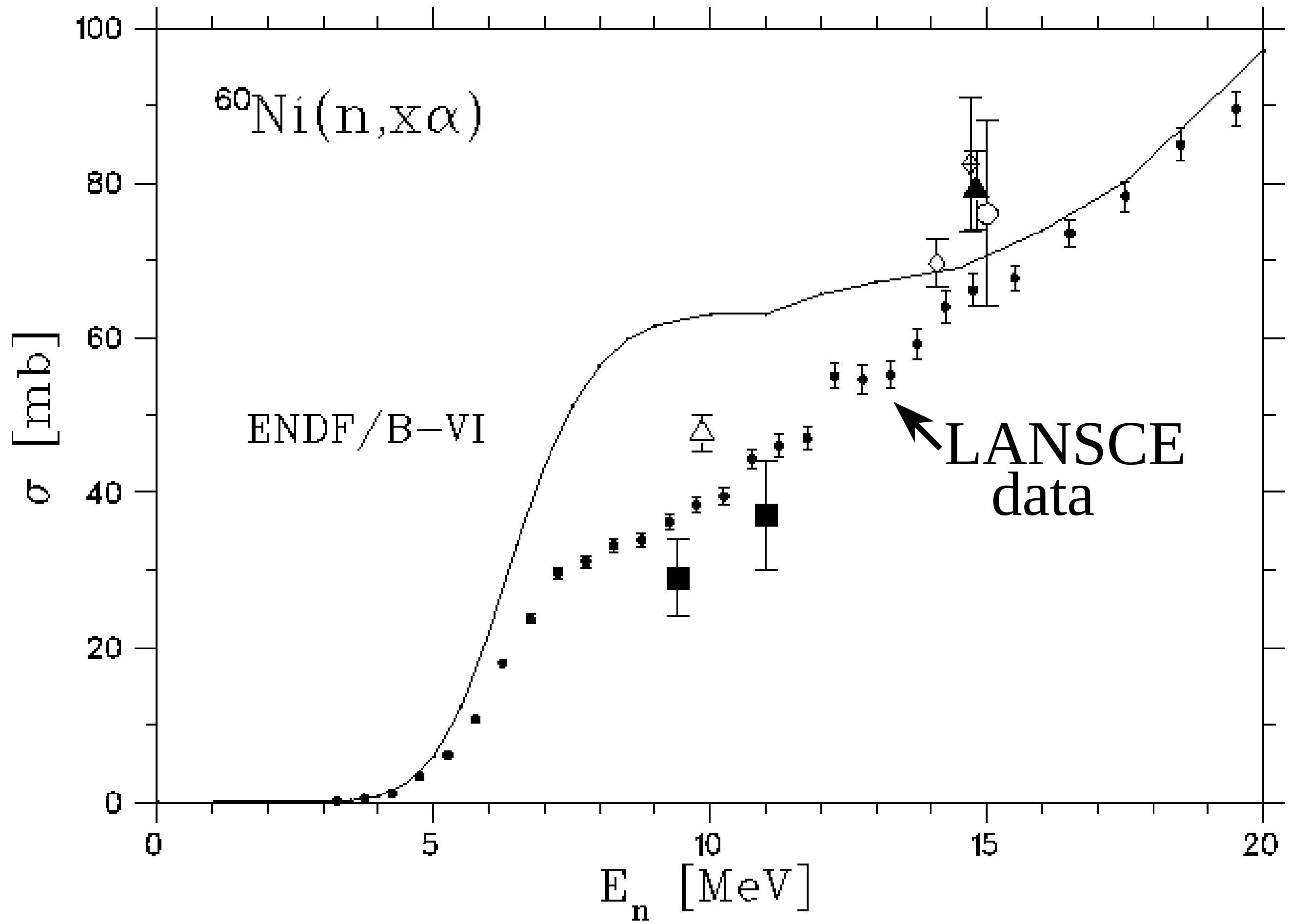
How are level densities measured?

RIA ?

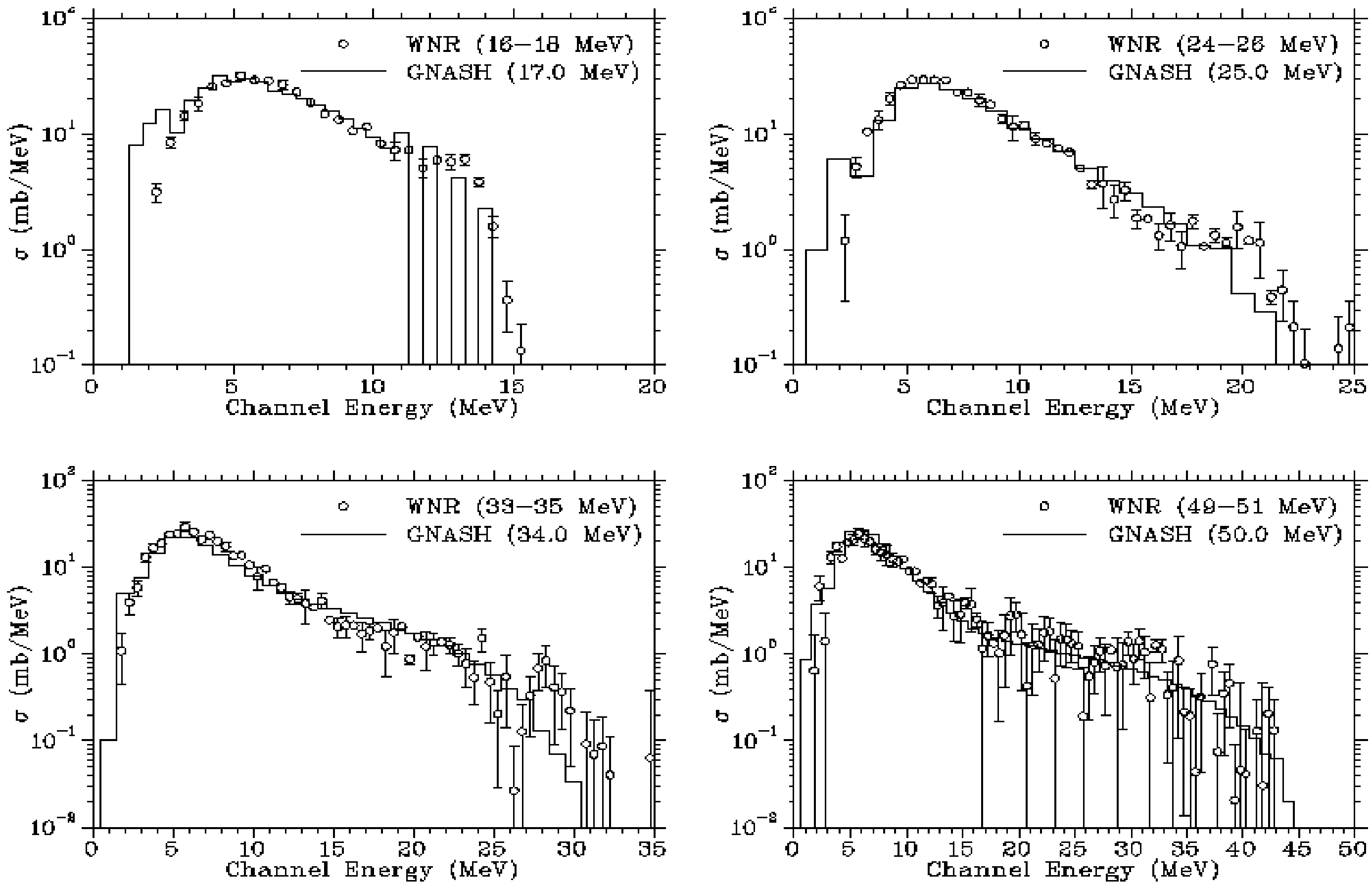
- Level counting --- > low excitation in nucleus — y
- Neutron resonances --- > small region of excitation energy just above the neutron separation energy — n
- Fluctuations of cross sections (Ericson fluctuations) --> several MeV above particle separation energy — ?
- Particle evaporation spectra ---> low energies to particle separation energy — y
- Excitation functions ---> relative level densities for competing channels; can go to very high excitation energies — y

Example of wrong level density (ENDF)



…. and not so bad level densities --

Si + n -> alpha-particle emission cross sections, which are well described by GNASH calculations



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Outstanding problems in nuclear level densities

- Structure in level densities ?
  - Calculations suggest that there is
  - Transition from ordered levels to disordered Fermi gas guarantees it -- at least up to some excitation energy
- Level densities at high excitation -- where shell and collective effects should wash out
- Angular momentum dependence of level densities
- Parity ratios
- Level densities for nuclides far from stability

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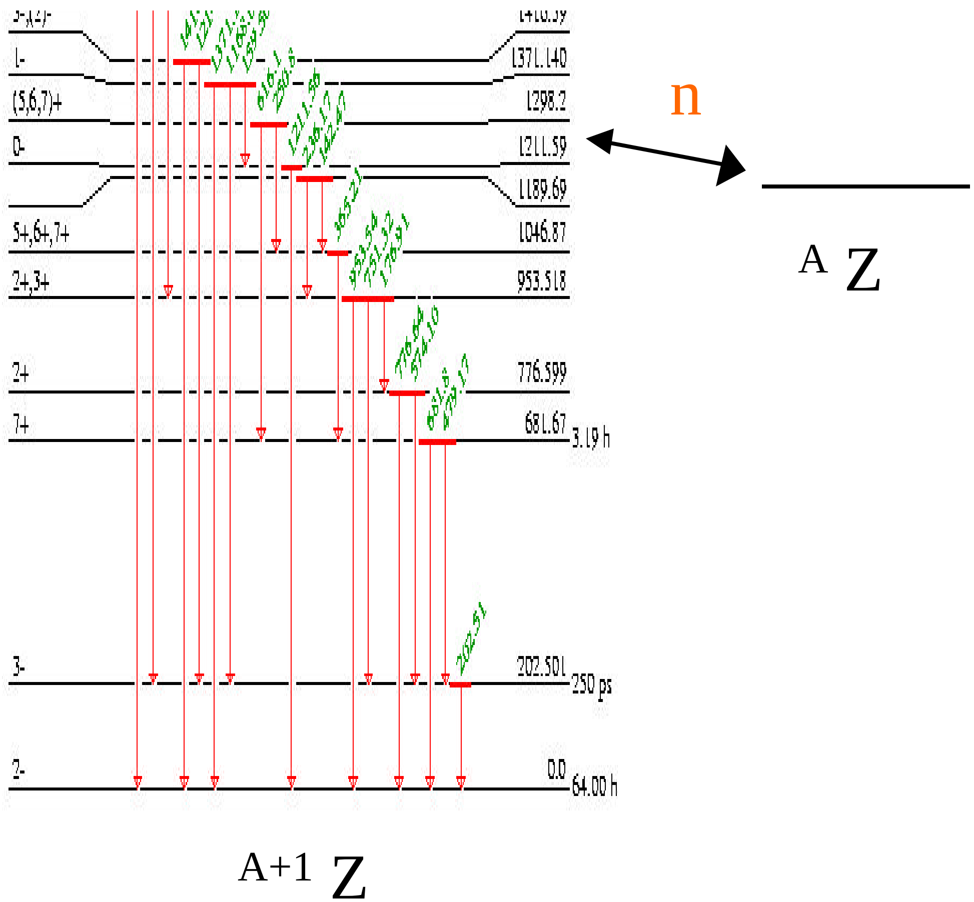
Level density can be very low at neutron separation energy for neutron-rich nuclides

Nuclear levels in a "typical" nucleus very far from the valley of stability

There sure are a lot fewer bound levels and level density for resonance neutron capture is very low!!



How can RIA be used to address these problems ?

- Unstable nuclides easily available
  - allows systematic studies across wide range of isotopes
- Beams of nuclides well suited for experiments in inverse kinematics
- Experimental approaches will be extensions of proven techniques

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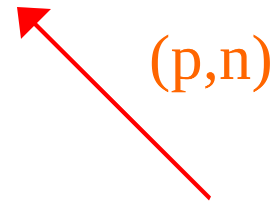
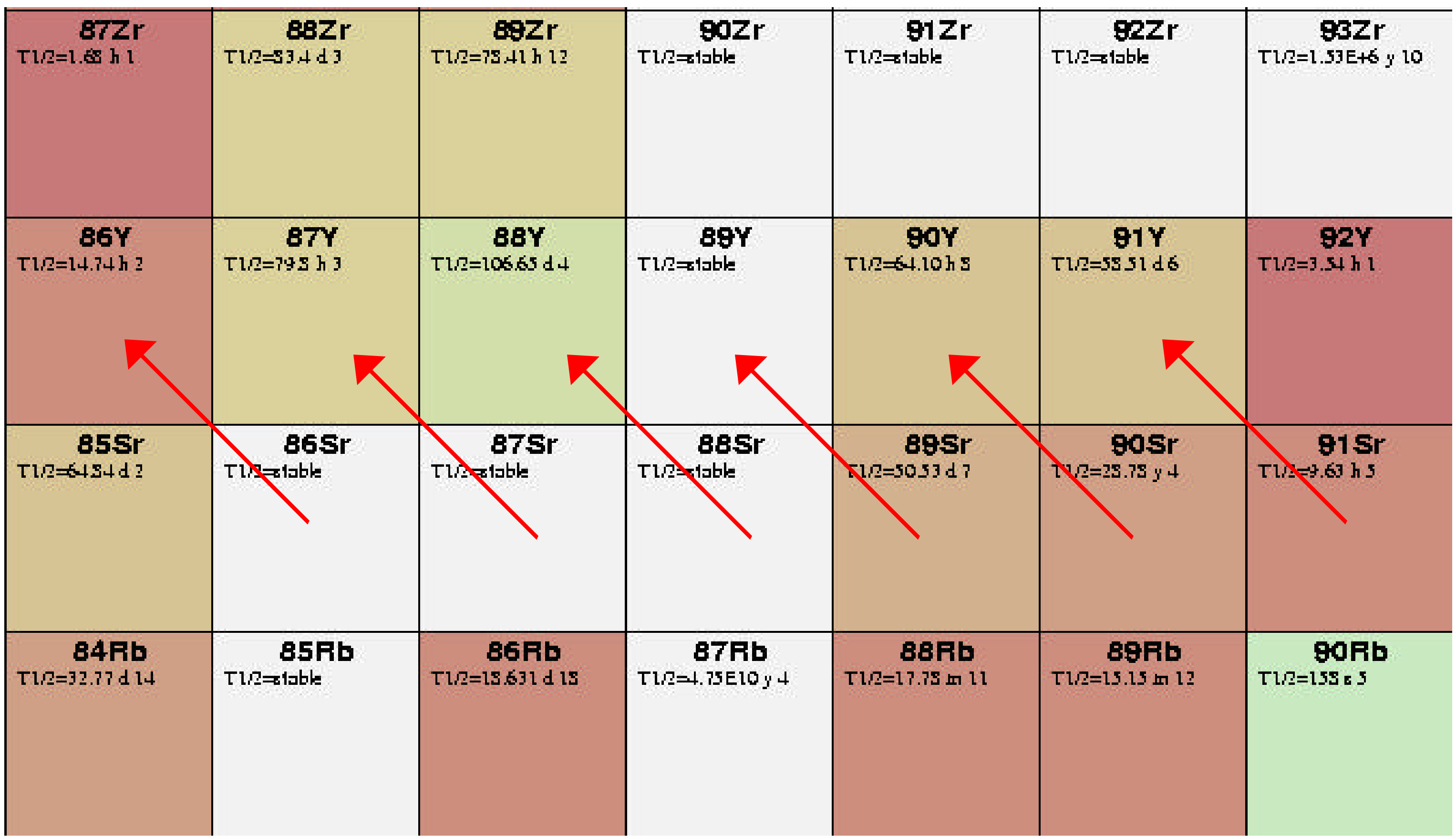
Get level densities through (p,n) reactions in inverse kinematics by measuring neutron emission spectra





Consistent set of data with calibration points (resolved levels, ^{89}Y + n resonances, etc.)

Relative level densities are indicated by competing channels, which are easily distinguished

example:

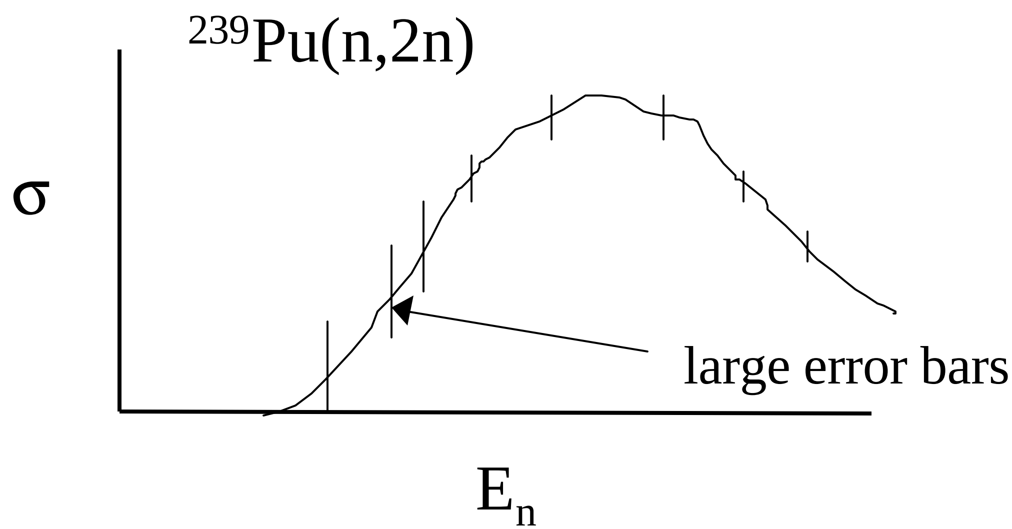
$$^{89}Sr + p \;\text{-->}\; ^{89}Y + n$$

$$\text{or} \quad ^{86}Rb + \alpha$$

$$\text{or} \quad \ldots$$

Then, in inverse kinematics, the products all go forward and can be collected. Ratios of cross sections will result.

Fission depends on level density at the fission barrier



$^{239}Pu + d \; \text{-->} \; ^{240}Pu^* + p$ (E_p tags Pu excitation)

→ $^{238}Pu + 2n$

→ fission

Collect the products

Inverse kinematics is crucial to this approach!

…. or

$$^{238}U + {}^{3}He \dashrightarrow {}^{240}Pu^{*} + n$$

etc.

Conclusions

- RIA will be used to study nuclear level densities far from stability
  - level counting
  - emission spectra
  - cross sections for competing channels
- SBSS could benefit greatly from this increased understanding
  - will the studies be in the region of our interests?