Physics opportunities with AIRIS beams

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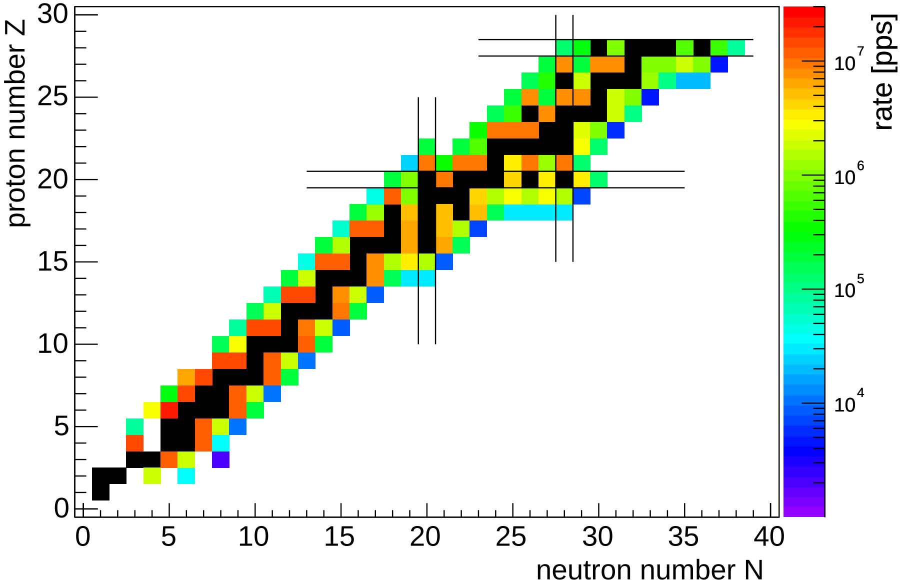
AIRIS rates


proton number Z
neutron number N
rate [pps]
0
5
10
15
20
25
30
35
40
10^4
10^5
10^6
10^7

- intense beams one or two nucleons away from stability
- significant increase in intensity compared to present status
- heavier beams available
- radioactive beams to Gammasphere, GRETINA, FMA and more
- physics opportunities for single-particle structure and reaction experiments:
  - single- and two-nucleon transfer reactions
  - inelastic scattering (p,p′)
- challenges:
  - high level densities
- on the other hand
  - well-known level structure (in many cases)

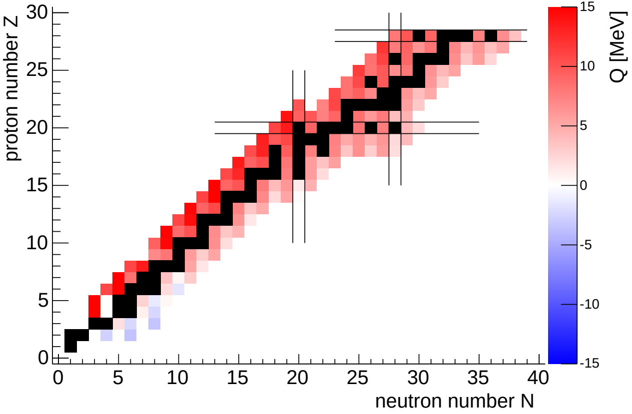
Requirements

Required experimental conditions for single-particle transfer experiments with radioactive beams

- beam intensity around 10^5 pps
- beam purity not so important, unless
  - total rate becomes to high
  - normalization relies on elastic scattering
  - high level density and overlapping recoil energy ranges
- small beam spot
- required energy resolution for recoils depends on level density
- detection of coincident γ radiation

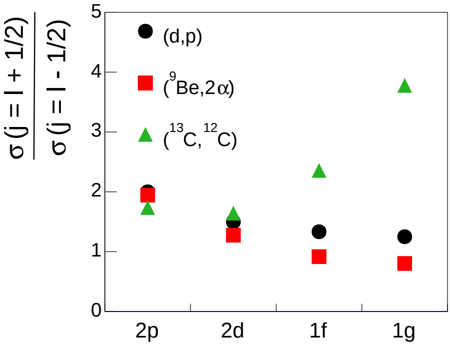
Q-value matching

- low Q-value preferred to populate low-lying states in (d,p) reactions
- HELIOS, silicon and γ-ray detector array, active target
- Q-value for (^{9}Be,2α) higher by $\approx$ 0.6 MeV



Heavy ion induced transfer reactions

- alternative targets are useful to study higher L orbitals (^{9}Be, 2α) and (^{13}C, ^{12}C) reactions
- particle trigger, γ-ray detection essential
- interpretation of angular distributions difficult
- relative cross section to $j = l + \frac{1}{2}$ and $j = l - \frac{1}{2}$ orbitals depends on target choice



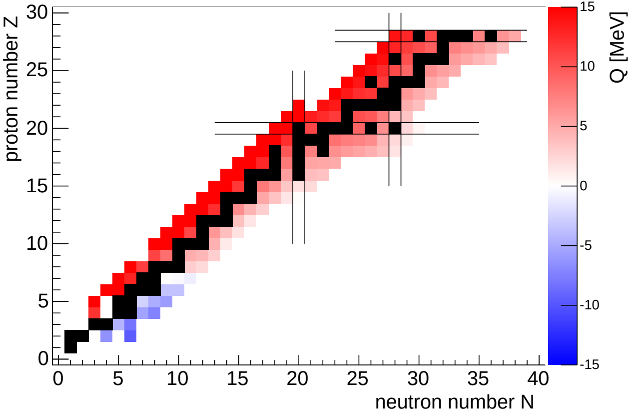
- ^{9}Be ground state 1$p_{3/2}$
  $\rightarrow \sigma$ larger for $j = l - \frac{1}{2}$ orbitals
- ^{13}C ground state 1$p_{1/2}$
  $\rightarrow \sigma$ larger for $j = l + \frac{1}{2}$ orbitals

Two-neutron transfer reactions

- Tritium loaded titanium foil targets

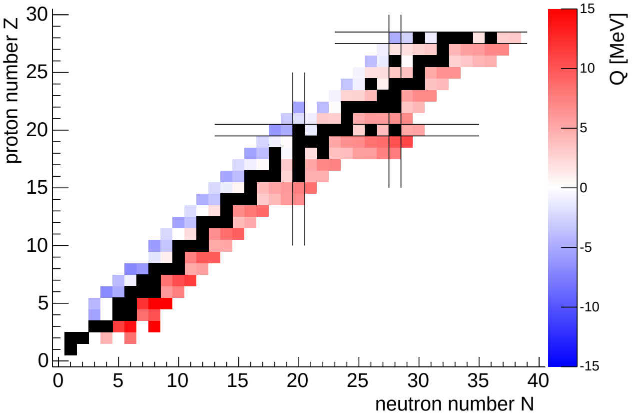
K. Wimmer et al., Phys. Rev. Lett. **105** 252501 (2010)

- four experiments performed at REX-ISOLDE so far
- low level density, particle detection can be sufficient
- alternative: (^{10}Be, 2α) reactions



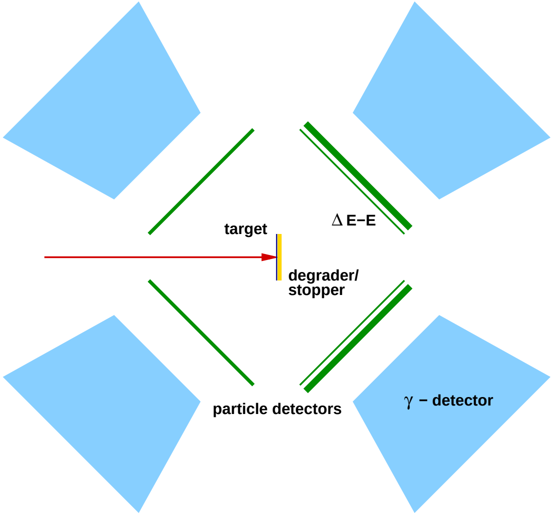
Proton-rich side

- proton transfer reactions for nuclear astrophysics
- (^{3}He,d) reactions to study (p,γ)

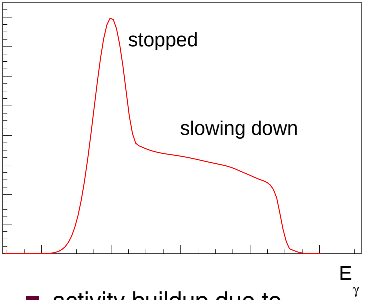


DSAM lifetime measurements

- lifetime of single-particle states
- (p,γ) resonances for nuclear astrophysics

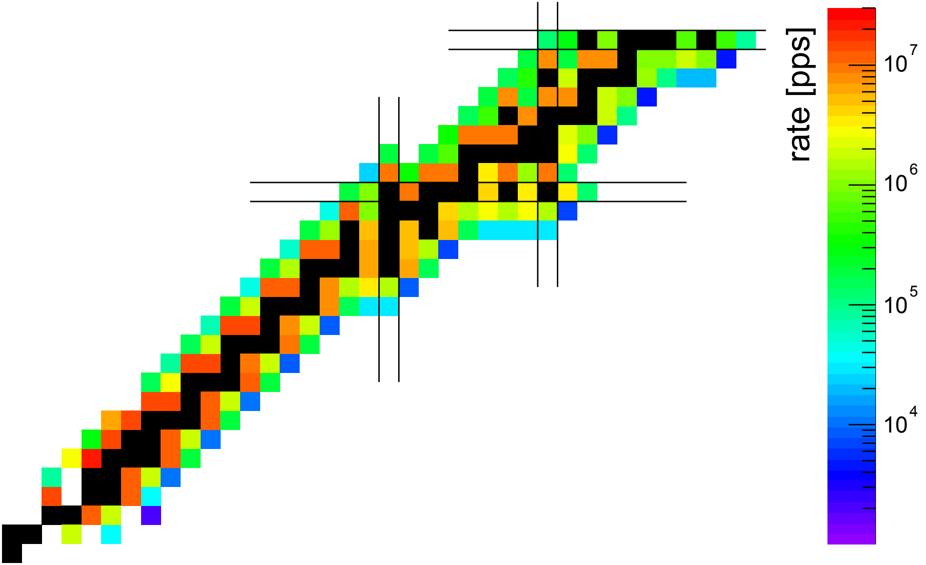


- ^{3}He or d implanted Au targets
- accesible lifetime ranges: 10 fs - 1 ps

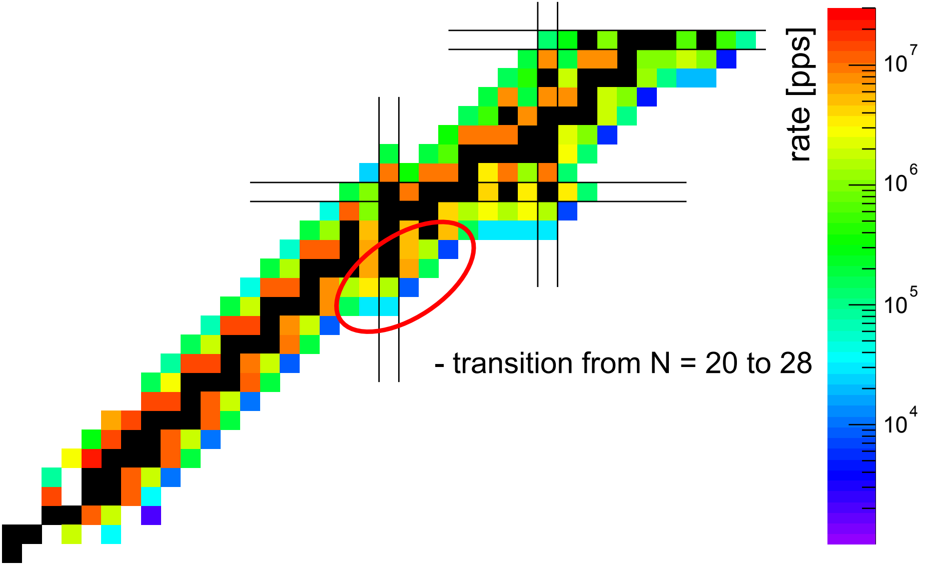


- activity buildup due to stopped beam
- close to stability gs $\rightarrow$ gs decays and low Q_β

Physics cases



Physics cases



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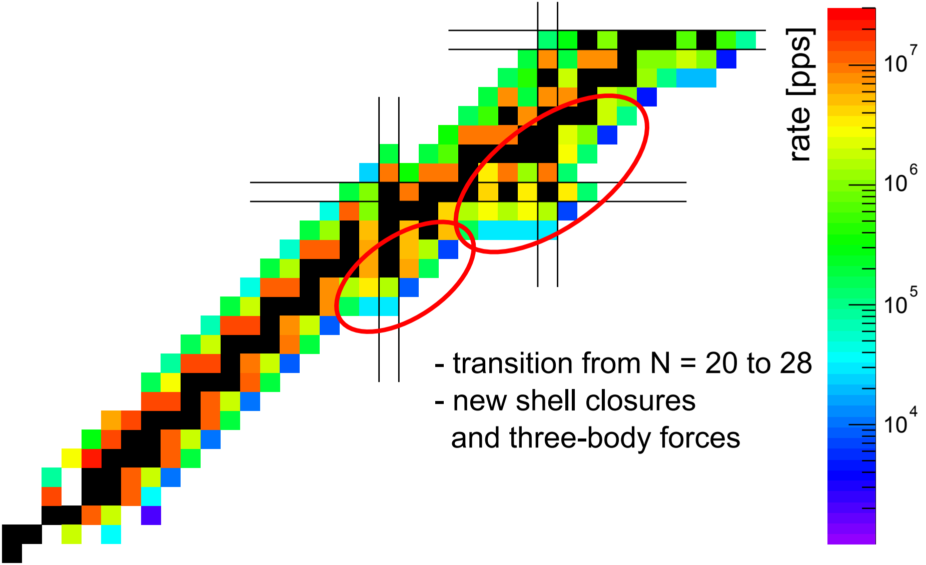

- transition from N = 20 to 28
- new shell closures and three-body forces

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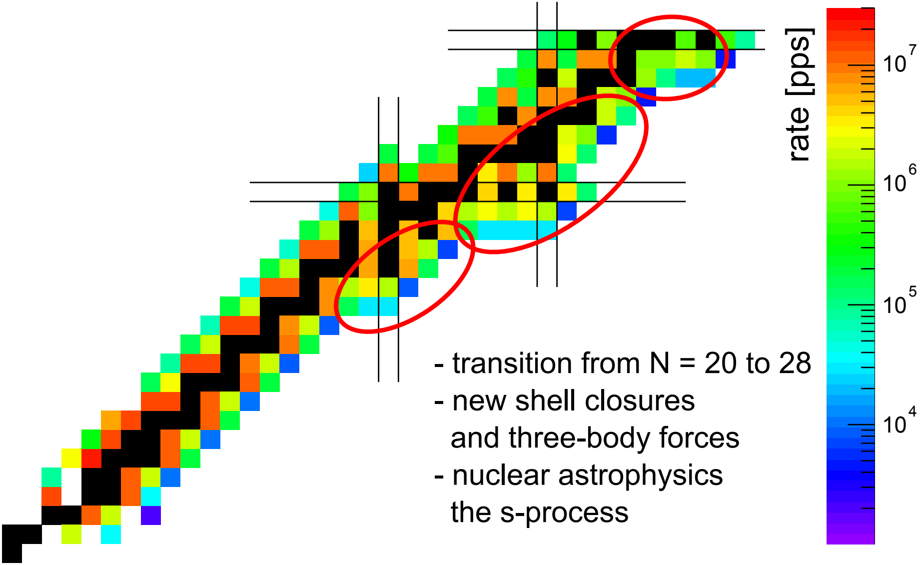
Physics cases

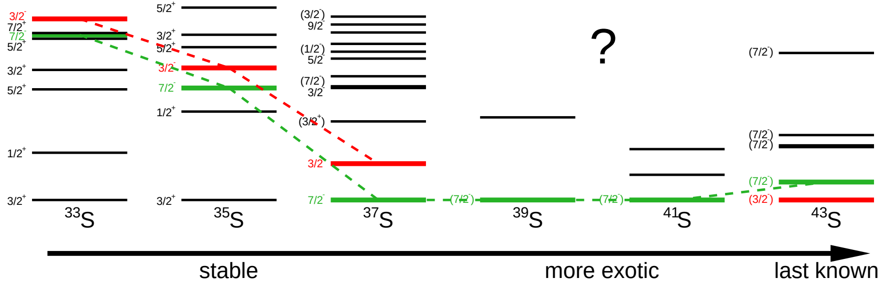


- transition from N = 20 to 28
- new shell closures and three-body forces
- nuclear astrophysics the s-process

From $N = 20$ to $N = 28$

Between the exotic $N = 20$ nuclei (Ne,Na,Mg) and the break down of the $N = 28$ shell closure in ^{42}Si the location of the $\nu f_{7/2}$ and $\nu p_{3/2}$ orbitals is influencing the properties of nuclei

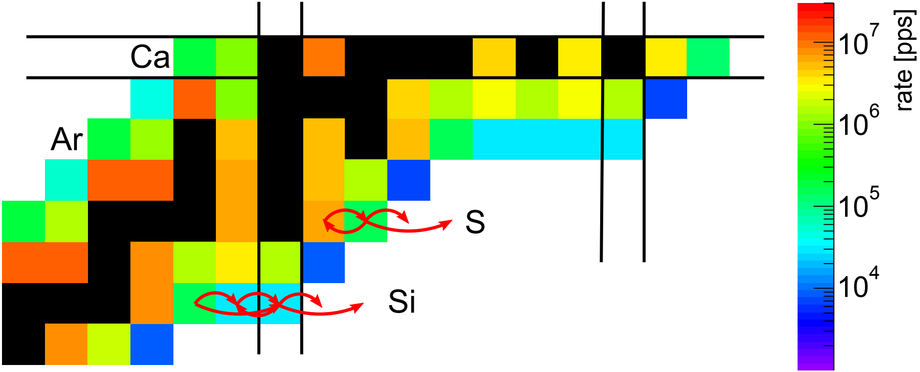
- study single-particle properties in Si and S
- little is known about the odd Si and S isotopes



From $N = 20$ to $N = 28$

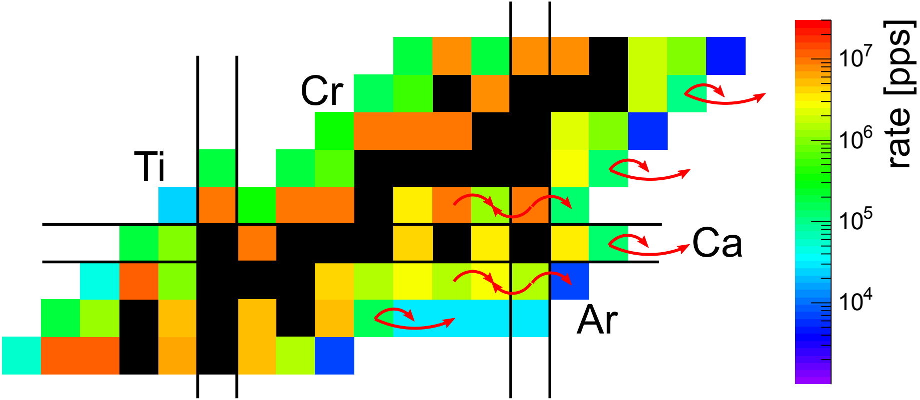
Possible experiments:

- Systematic study of single-particle orbitals at $N = 21, 23$ in Si and S
- (d,p) and (p,d) transfer reactions to locate single-particle/hole strength
- heavy ion induced transfer for the $L = 3$ neutron $f_{7/2}$ orbital
- two-nucleon transfer reactions, t(^{32}Si,p) at $N = 20$



$N = 28 - 34$ and three-body forces

- difficult region for ISOL facilities
- three-body forces are essential to describe the $N = 28$ shell gap
  single-particle transfer with K and Sc at $Z = 19, 21$
- sub-shell closures at $N = 32, 34$
  (d,p) and (t,p) reactions with Ca, Ti, and Cr

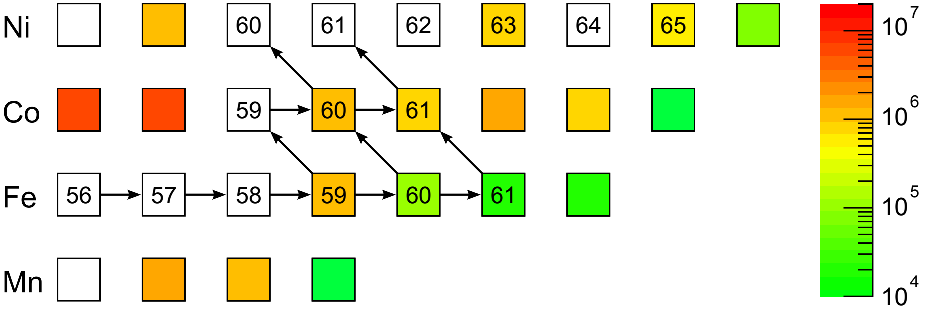


Nuclear astrophysics

- s-process branching in the long lived ^{59}Fe, ^{60}Fe, ^{60}Co
- calculated production of ^{60}Fe in heavy stars varies by orders of magnitude

T. Rauscher and F.-K. Thielemann, At. Data Nucl. Data Tables **75** (2000) 1

- at high neutron densities, neutron capture on ^{59}Fe ($t_{1/2} = 44.5$ d) relevant
- ^{60}Fe (n,γ) measured directly ($t_{1/2} = 2$ My) E. Uberseder et al., Phys. Rev. Lett. **102** 151101 (2009)



- sufficient rates to study these branchings with AIRIS

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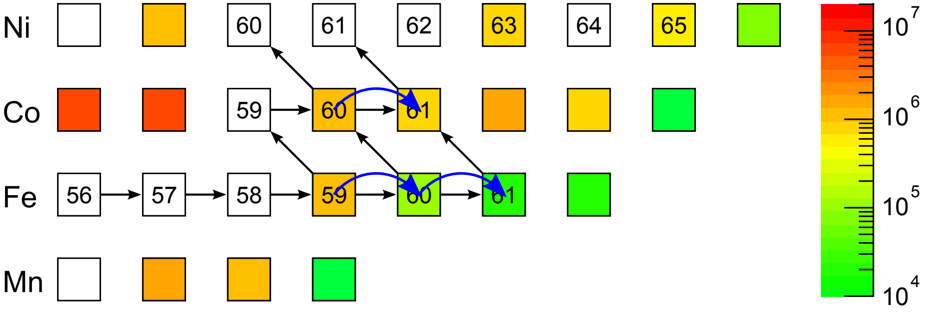

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Summary

- AIRIS offers significantly increased beam intensities
- beams that are not available at ISOL facilities
- unique possibilities for transfer reaction experiments
  (d,p), (t,p) and heavy ion induced transfer reactions
- (^{3}He,d) proton transfer for nuclear astrophysics
- new experimental techniques to investigate single-particle properties