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Nuclear binding energies and astrophysics motivation in the ^{78}Ni region

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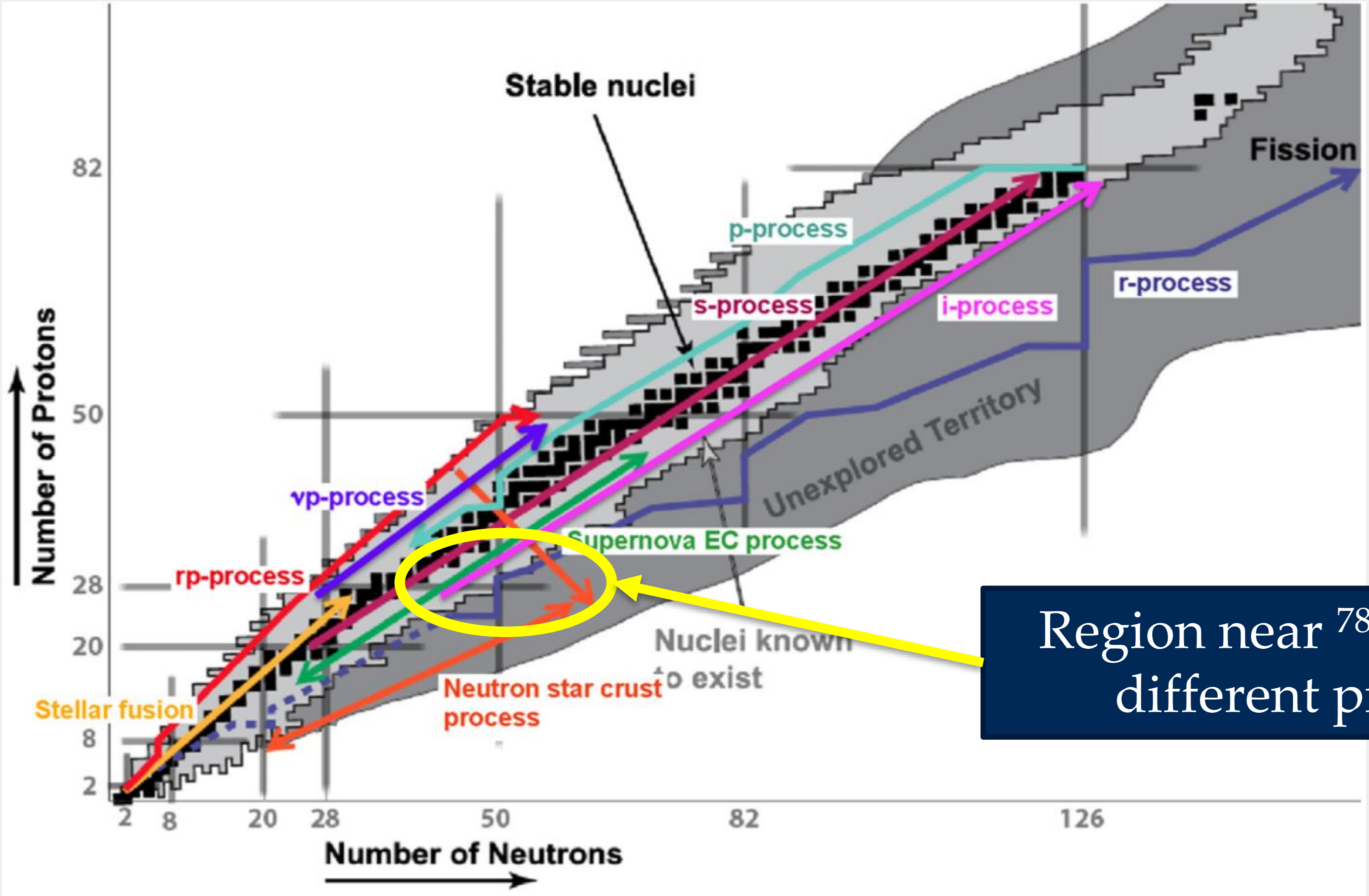
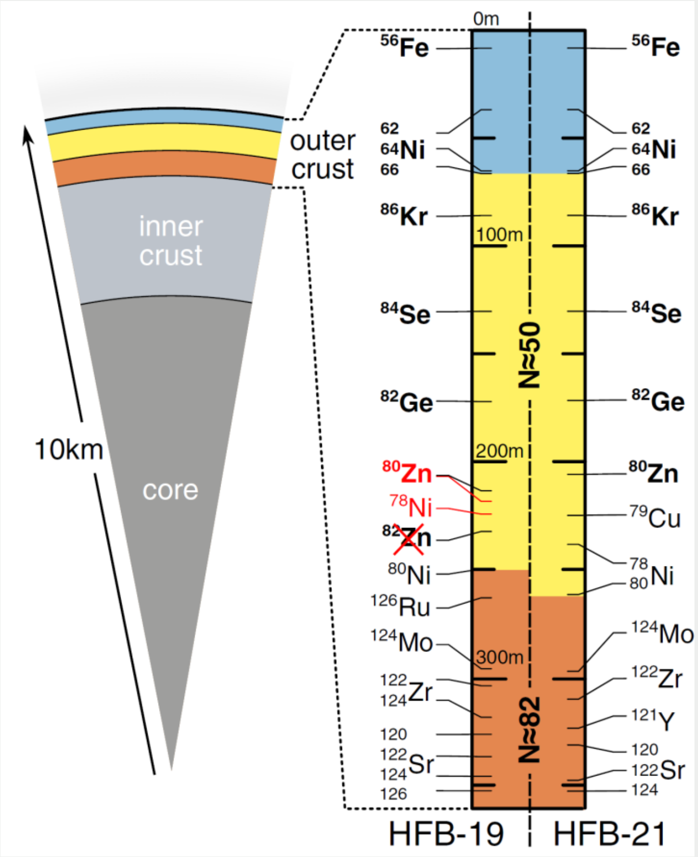
Astrophysical processes

H. Schatz, J. Phys. G: Nucl. Part. Phys. 43 (2016) 064001



Region near ^{78}Ni is rich of different processes!

Neutron star crust composition



R.N.Wolf et al., PRL 110, 041101 (2013)

Nuclei close to N=50 dominant in the outer crust at depth ~60-250 m.

Including new masses
→ effect on the composition

Astrophysical r process

Weak r process (A < 120)

- ν-driven winds from proto-neutron star in core-collapse supernovae
- MHD supernovae jets

Main r process (A > 120)

- Merger of two neutron stars -- confirmed by GW170817, GRB 170817A&AT2017gfo; see e.g. *Astrophys. J. Lett. 848, L12 (2017)*
- neutron star – black hole mergers?
- Other sites, such as magnetars?

Astrophysical r process

Weak r process (A < 120)

- ν-driven winds from proto-neutron star in core-collapse supernovae
- MHD supernovae jets

Also in neutron star mergers!
N.V. Tanvir et al., Astrophys. J. Lett. 848, L27 (2017)

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- Merger of two neutron stars -- confirmed by GW170817, GRB 170817A&AT2017gfo; see e.g. *Astrophys. J. Lett. 848, L12 (2017)*
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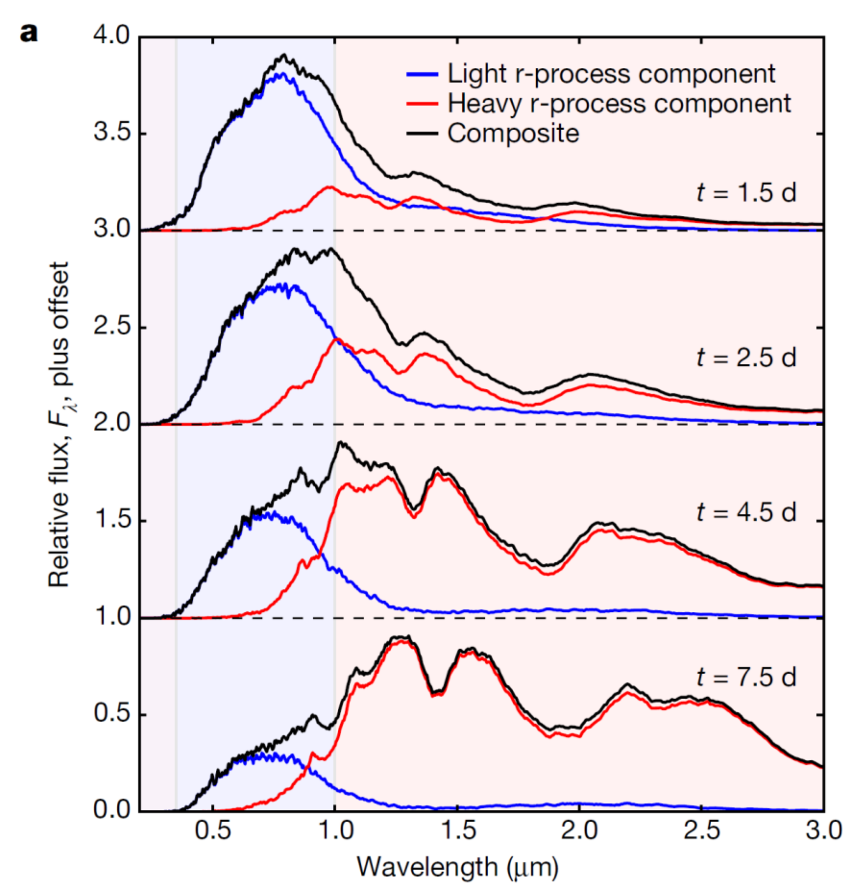
Kilonova associated with GW170817

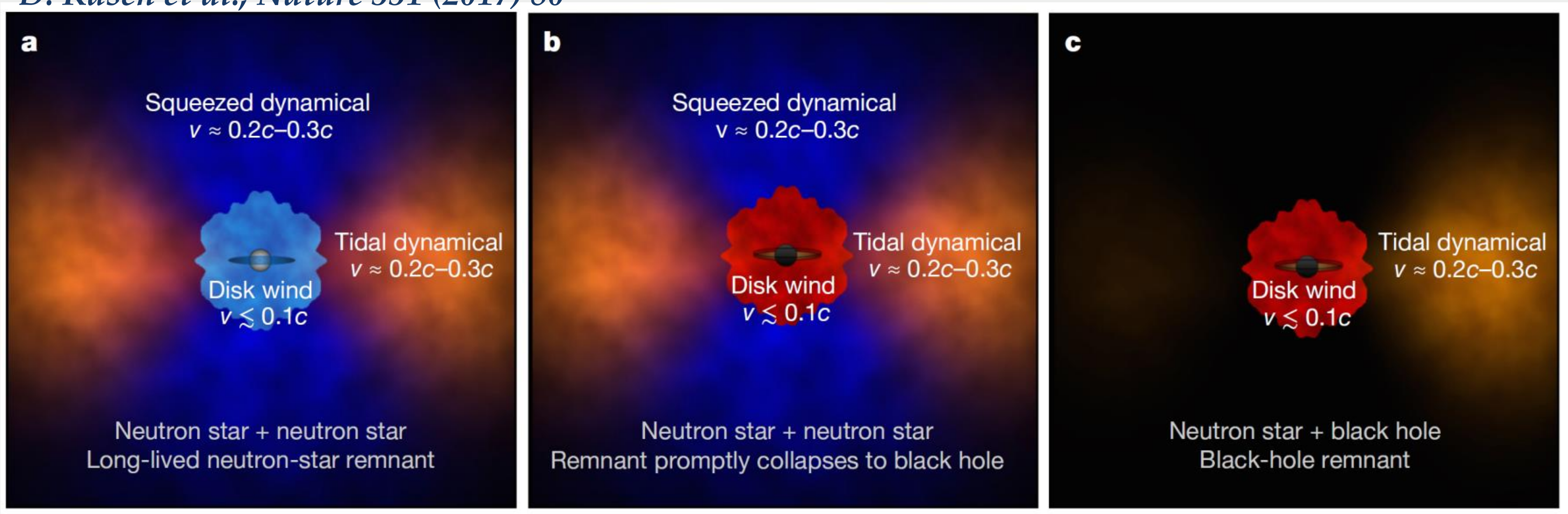
D. Kasen et al., Nature 551 (2017) 80



- Kilonova = thermal glow powered by radioactive decay of r-process nuclei
- Change from blue to red kilonova
- Two components:
  - A<140 (blue, lower opacity)
  - A>140 (red, higher opacity)

Production of lighter r-process elements

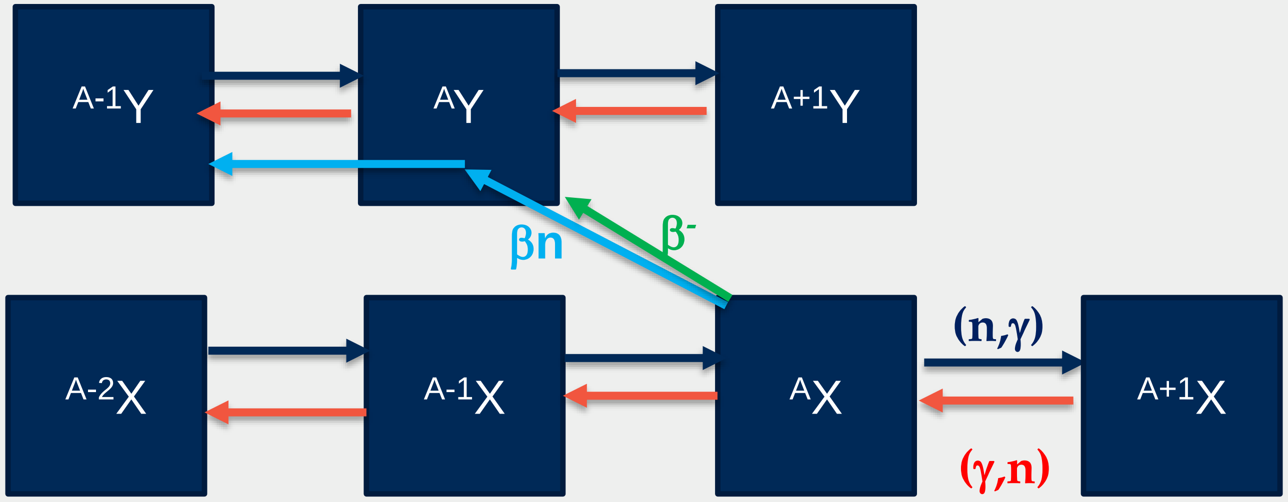
D. Kasen et al., Nature 551 (2017) 80



Wind ejecta can produce isotopes in the range between the 1st and 2nd r-process peaks, or even near the iron peak for particularly high Y_e values
Lippuner et al., MNRAS 472 (2017) 904–918

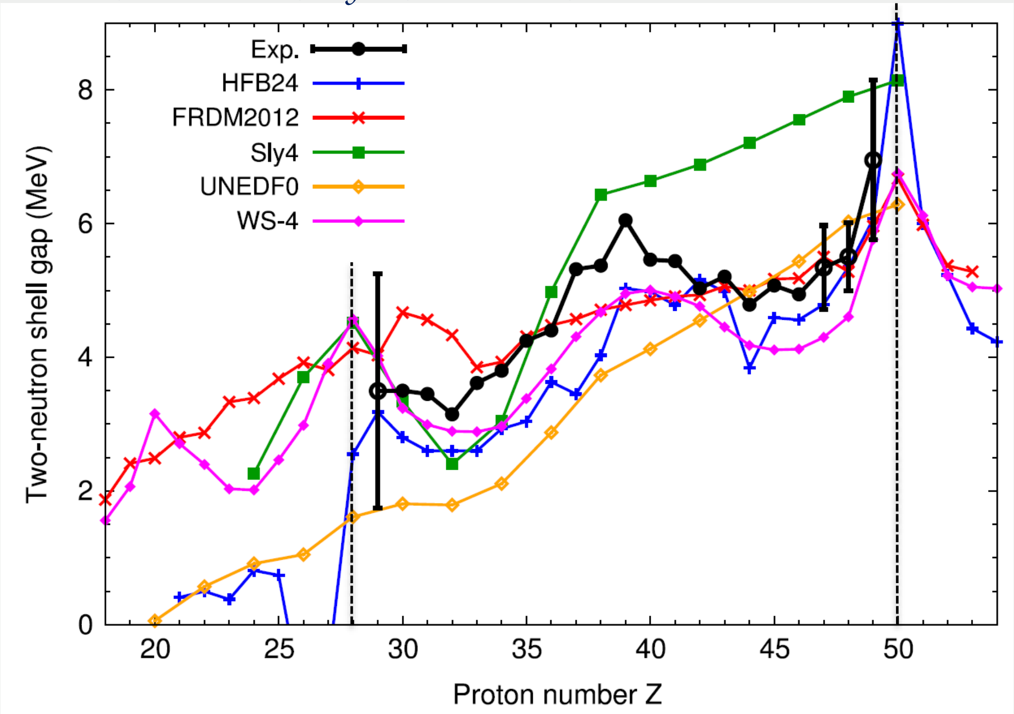
Nuclear physics inputs for the r process

Need:
- Nuclear masses
- Beta-decay $T_{1/2}$ and P_n values
- (n,γ) rates
- Fission properties for recycling



Neutron shell gap N=50

Eronen, Kankainen, Äystö, PPNP 91, 259 (2016)



Penning trap measurements in the region, e.g.

JYFLTRAP:

- S. Rahaman et al., EPJ A 34, 5 (2007)
- J. Hakala et al., PRL 101, 052502 (2008)
- L. Canete, S. Giraud et al.

ISOLTRAP:

- C. Guénaut et al., PRC 75, 044303 (2007)
- S. Baruah et al., PRL 101, 262501 (2008)
- A. Welker et al., PRL 119, 192502 (2017)

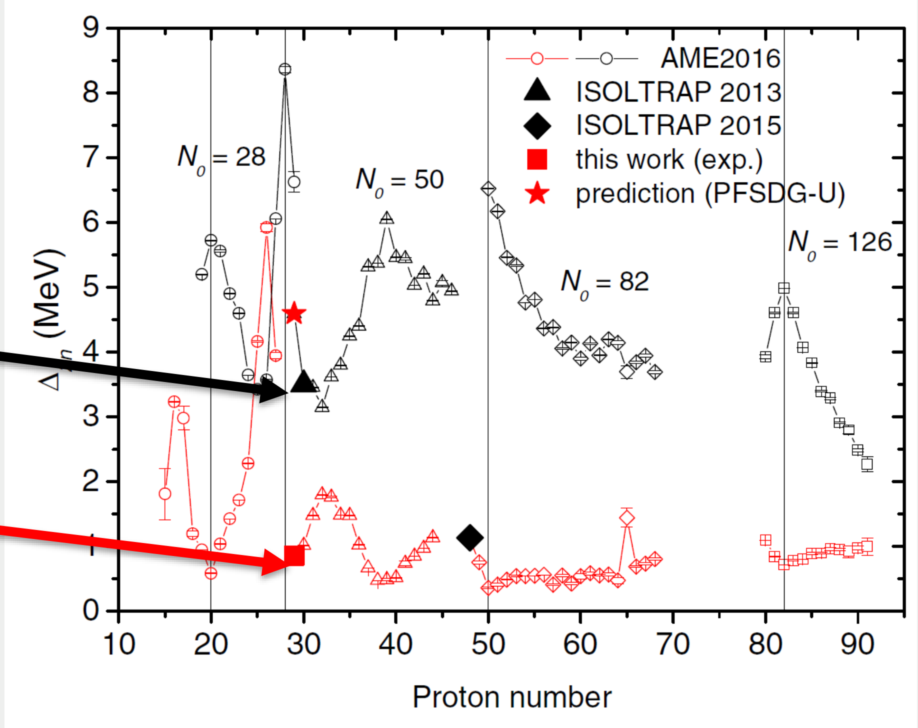
Measurements with ISOLTRAP at ISOLDE

^{79}Cu measured but ^{81}Cu unmeasured – N=50 shell gap at Z=29 extrapolated but:

A. Welker et al., PRL 119, 192502 (2017)

$$\Delta_{2n}(Z, N_0) = S_{2n}(Z, N_0) - S_{2n}(Z, N_0 + 2)$$

$$\Delta_{2n}(Z, N_0 - 2) = S_{2n}(Z, N_0 - 2) - S_{2n}(Z, N_0)$$

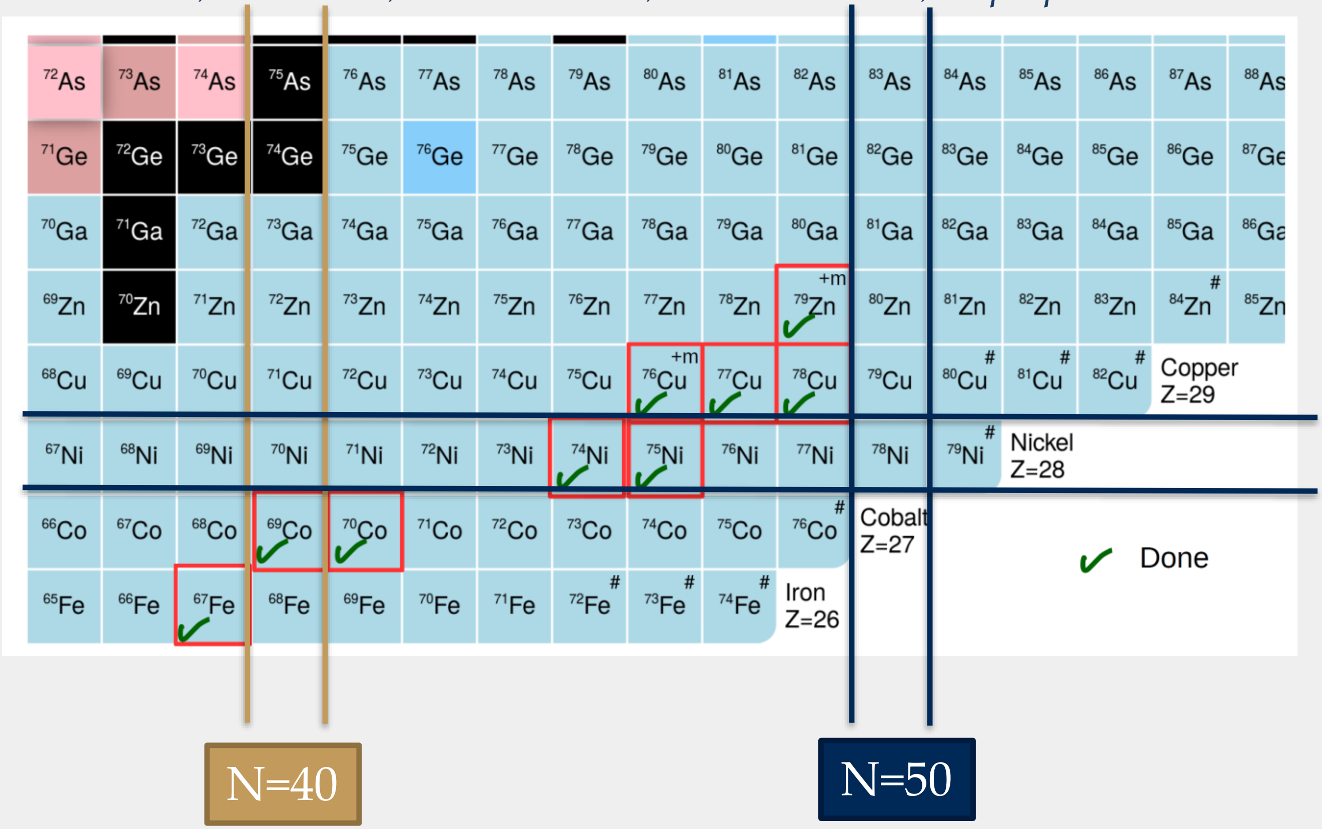


New shell-model interaction PFSDG-U fits well with the measured masses
F. Nowacki et al., PRL 117, 272501(2016)

Measurements with JYFLTRAP at IGISOL

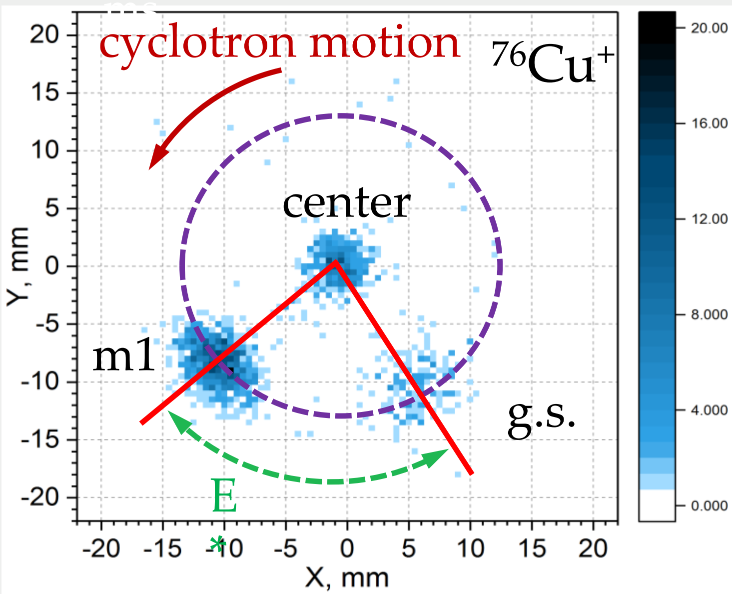
35 MeV p on ^{nat}U
Measured several new isotopes close to N=40 and N=50

L.C. Canete, S. Giraud, A. Kankainen, B. Bastin et al., in preparation

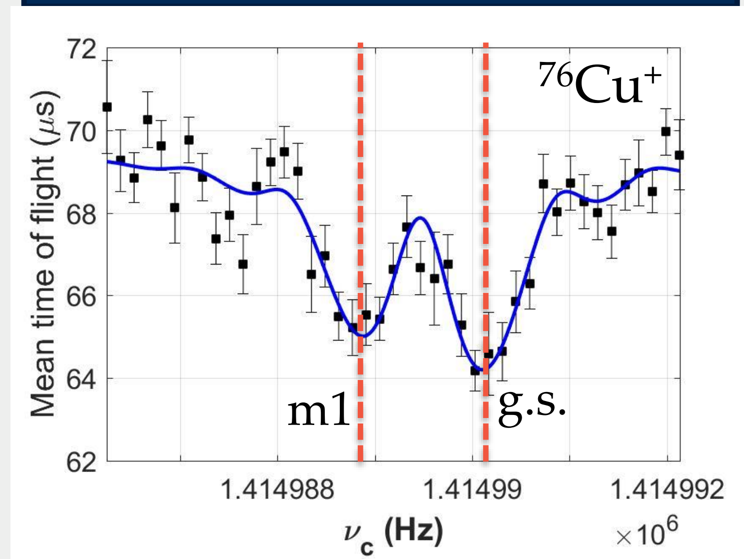


Isomeric states revealed with PI-ICR

JYFLTRAP: PI-ICR, $t_{acc} = 200$



JYFLTRAP: TOF-ICR, $T_{RF} = 1120$ ms



JYFLTRAP: $T_{1/2}$(g.s.) > $T_{1/2}$(m1)

$J^{\pi} = (1,3)$ $T_{1/2} = 1.27(30)$ s

Nubase 2016

E* = 0#(200#) keV

?

$J^{\pi} = (3,4)$ $T_{1/2} = 637.7(55)$ ms

ME = -50976(7) keV

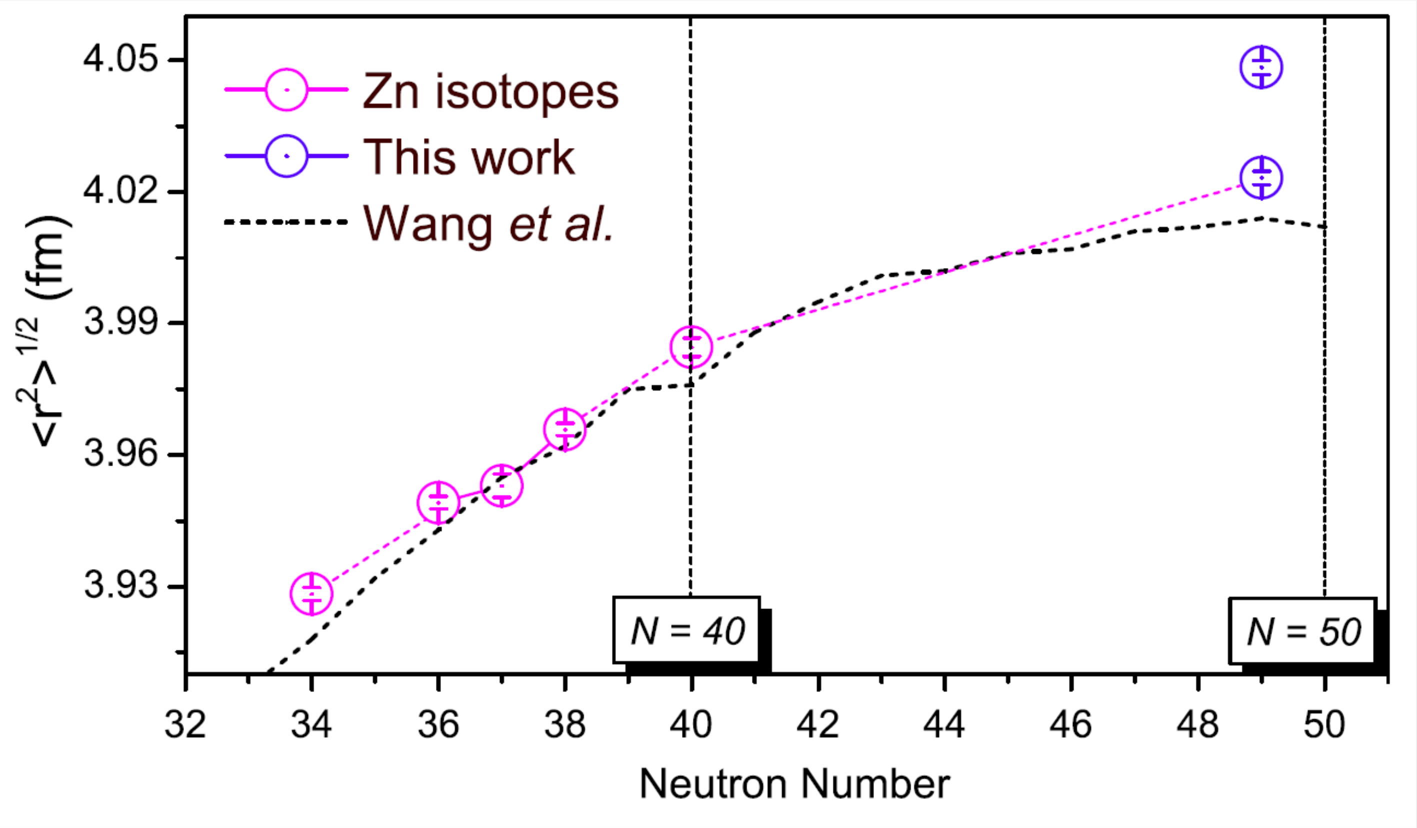
^{76}Cu

Two half-lives (TRISTAN):
J. A. Winger et al, PRC 42, 954 (1990).

Mass of ^{76}Cu (ISOLTRAP):
C. Guenaut et al., PRC 75, 044303 (2007);
A. Welker et al., PRL 119, 192502 (2017).

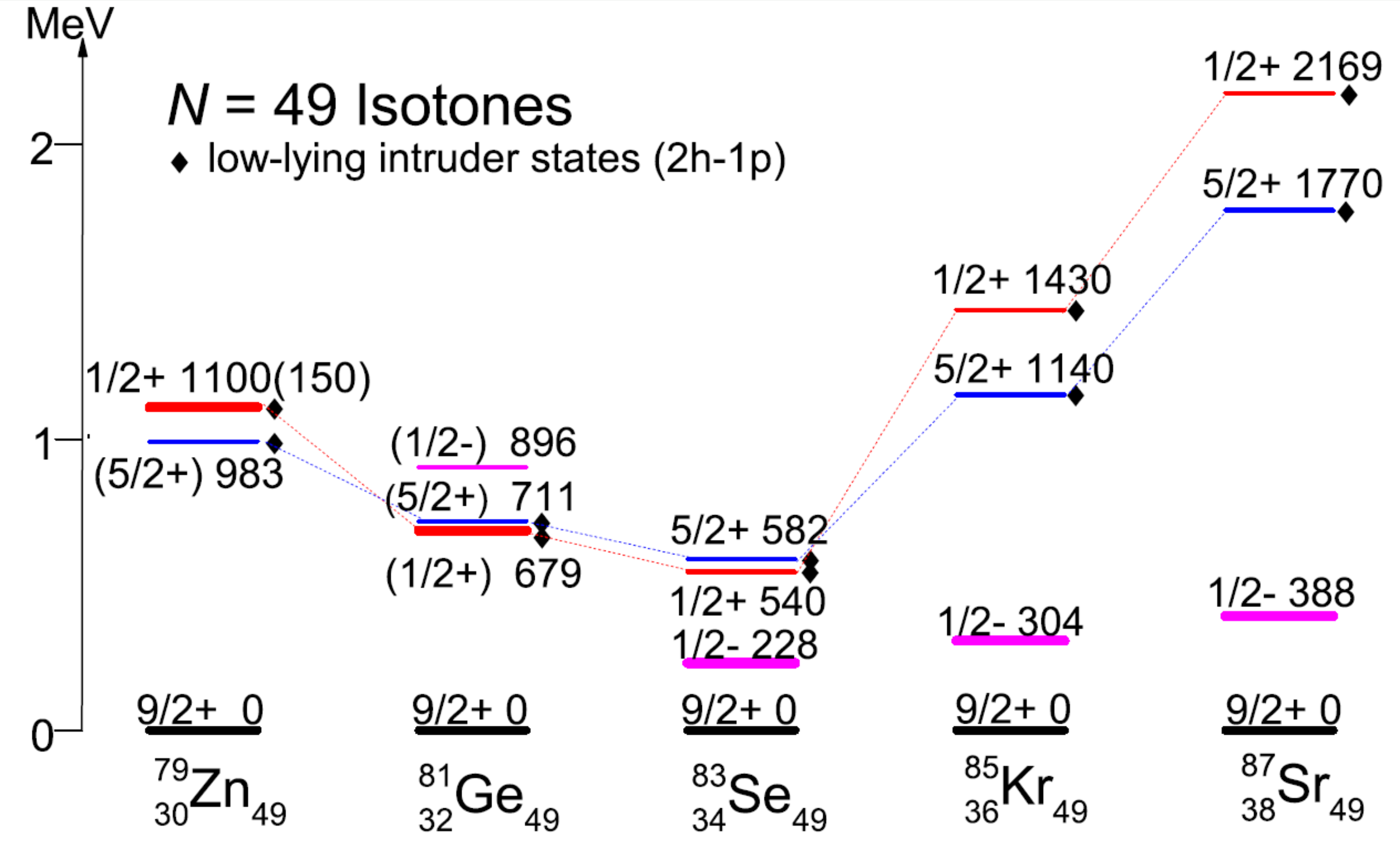
Shape coexistence: $^{79}Zn^{m}$ (1/2+)

Collinear laser spectroscopy at ISOLDE



X. F. Yang et al. PRL 116, 182502 (2016)

Systematics of N=49 isotones

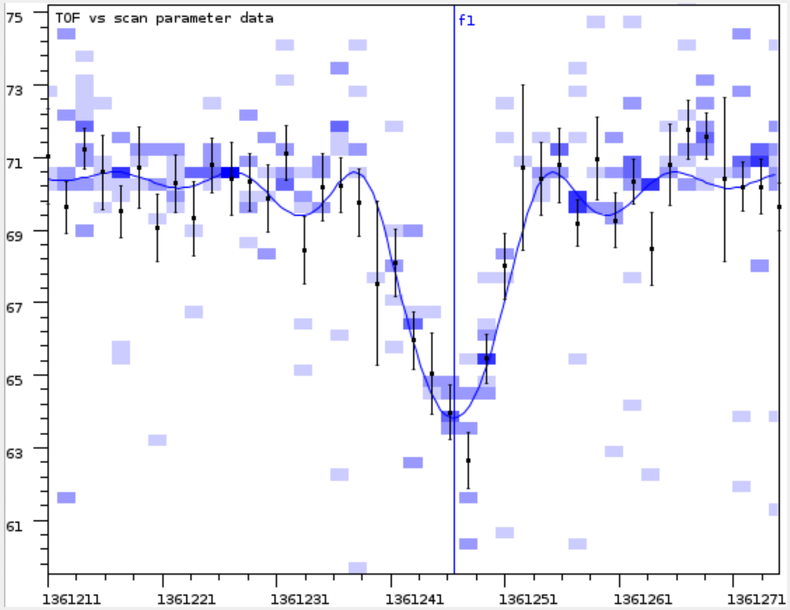


X. F. Yang et al. PRL 116, 182502 (2016)

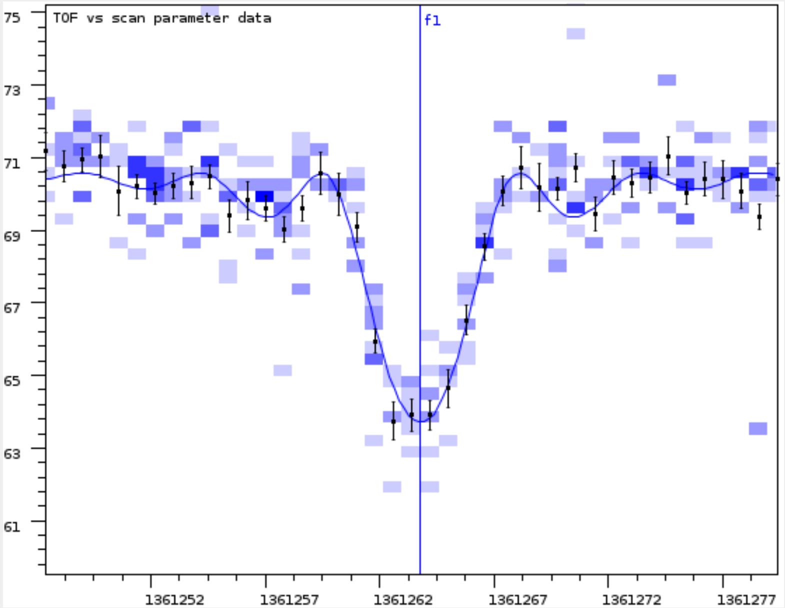
Shape coexistence: masses

Mass measurements at JYFLTRAP → excitation energy for the isomer

Tof-ICR ^{79m}Zn



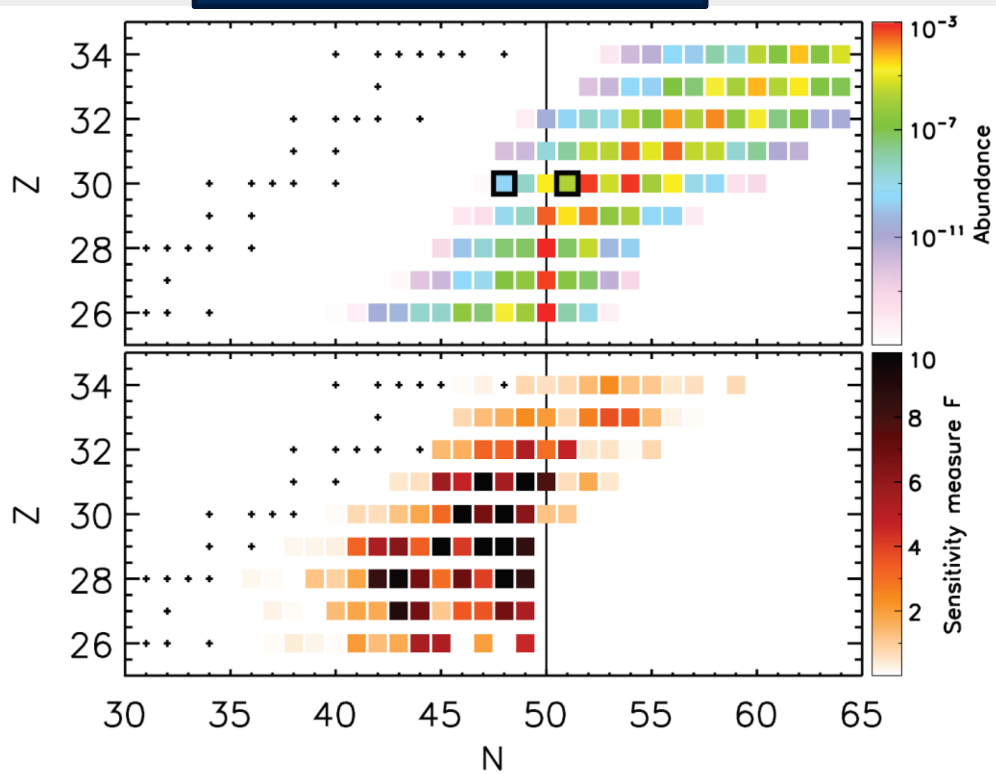
Tof-ICR ^{79}Zn



L.Canete, S. Giraud, AK, B. Bastin et al., in preparation

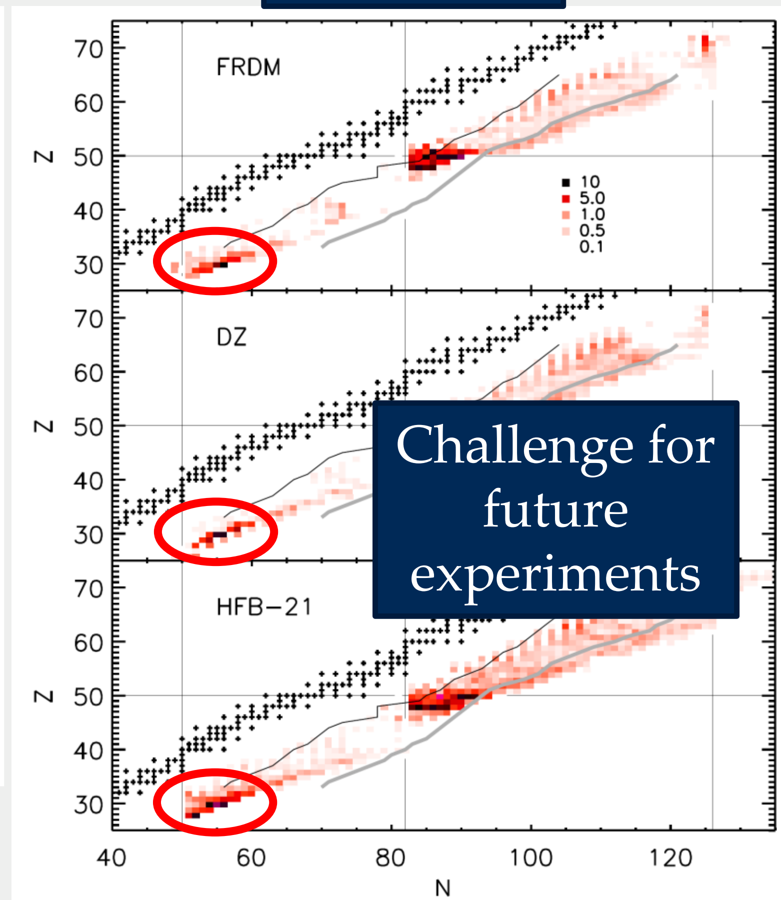
Outlook: sensitivity studies

Neutron capture rates



R. Surman et al., AIP ADVANCES 4, 041008 (2014)

Mass values



Challenge for future experiments

S. Brett et al., Eur. Phys. J. A 48, 184 (2012)

Note: masses (Q-values) impact also the calculated neutron-capture rates.

Summary and outlook

- Toward more neutron-rich exotic nuclei close to ^{78}Ni
- Mass measurements using Penning trap techniques and MR-TOF mass spectrometers at ISOLDE, IGISOL, ALTO,…
- Long-living isomeric states and their role
- Purified beams for decay spectroscopy (beta-delayed gammas and neutrons, half-lives, …)
- Neutron-capture rates: (d,p), beta-Oslo method,…
- Interesting region for EURISOL-DF!

Acknowledgments

IGISOL group
www.jyu.fi/igisol

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