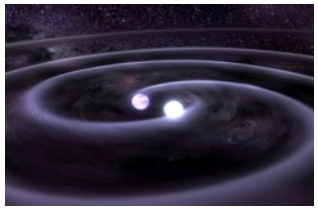
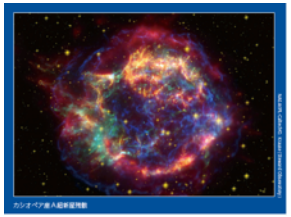
EMMI Rapid Reaction Task Force: The physics of neutron star mergers at GSI/FAIR

07 June , 2018

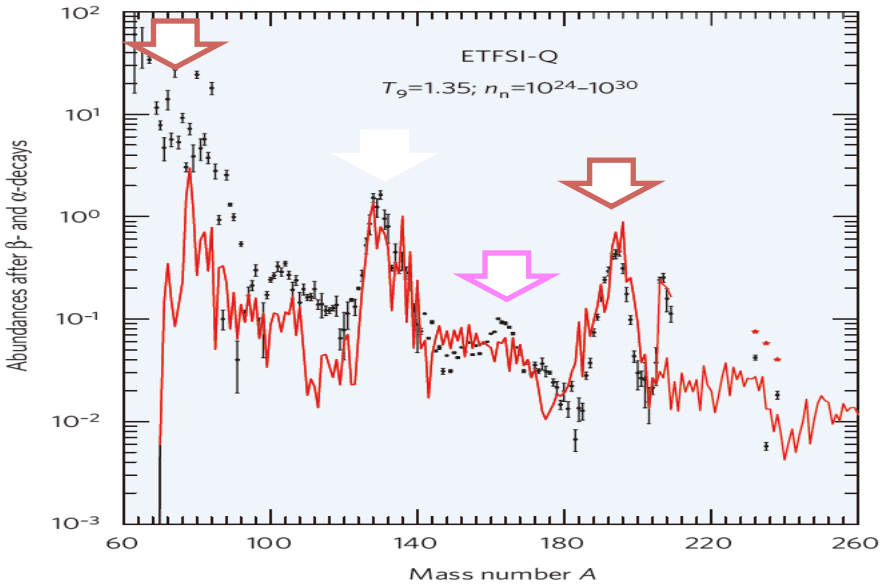
Experimental nuclear physics for the r-process (Discussion)

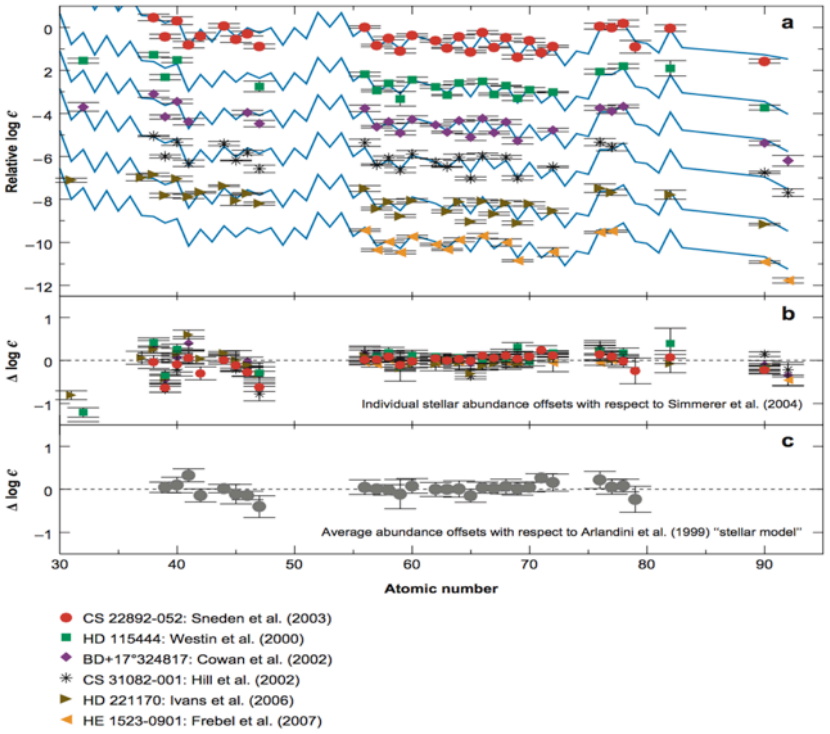




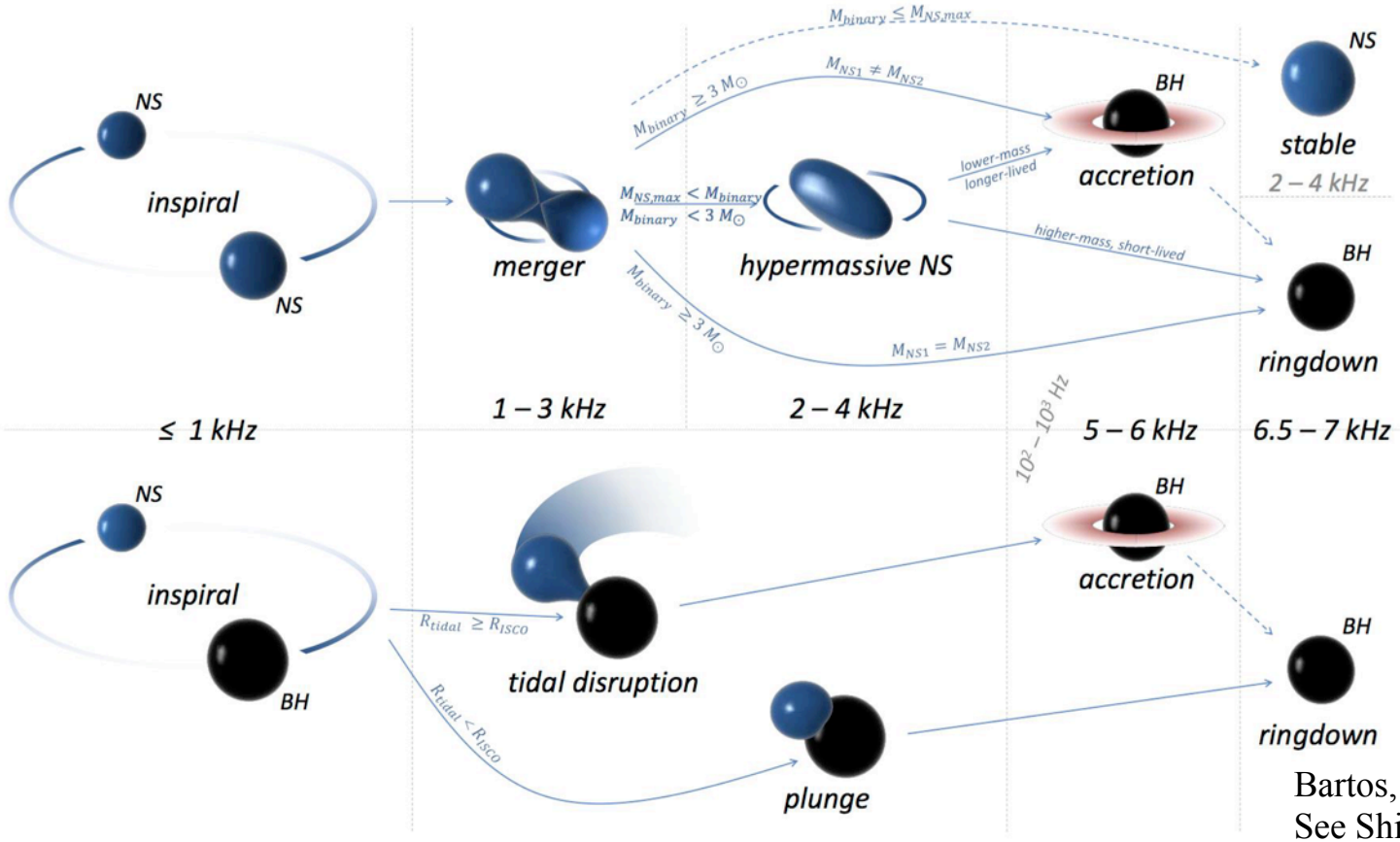
S. Nishimura
RIKEN Nishina Center

J.J.Cowan C.Sneden, Nature 440 (2006)





from Brian's talk



Bartos, Brady, Marka2013
See Shibata et al. 2005, 2006

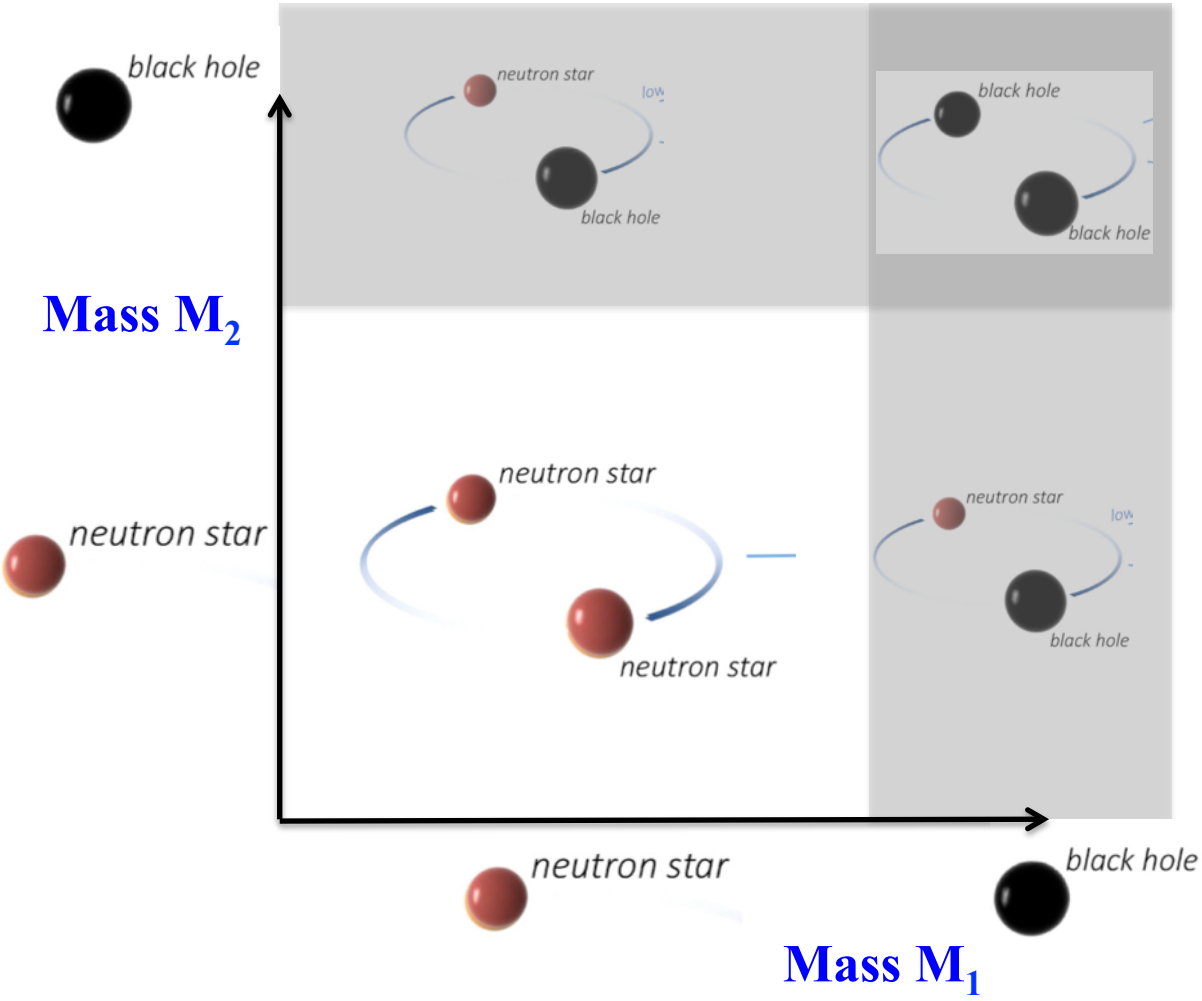
[NS-NS] 1 event
[NS-BH] 0 event

→ 10 → 10^2 → 10^3 events

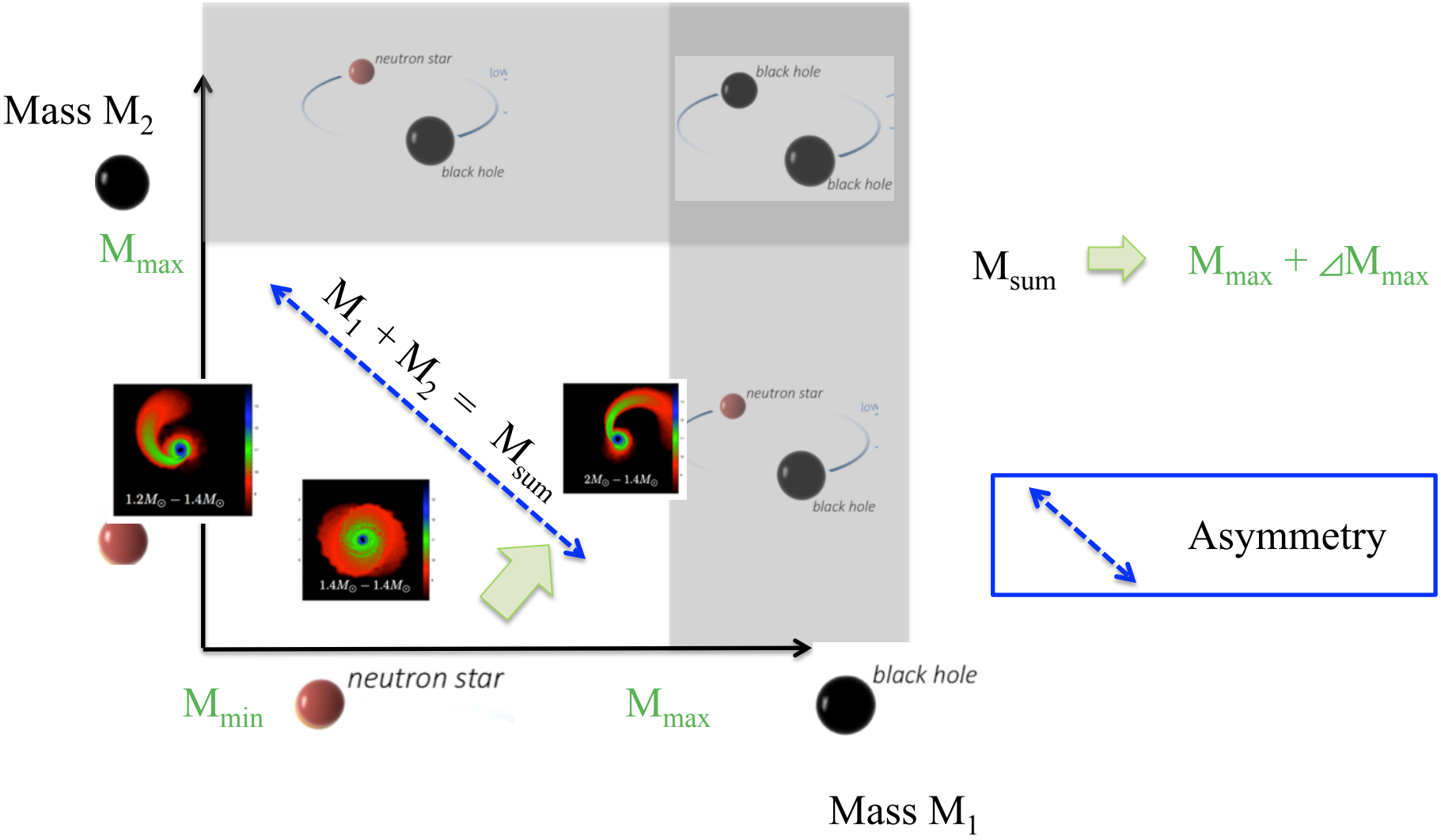
What kinds of New Information Expected !?

⟺ Nuclear Physics

Mapping of “NS-NS”, “NS-BH” Merger Events



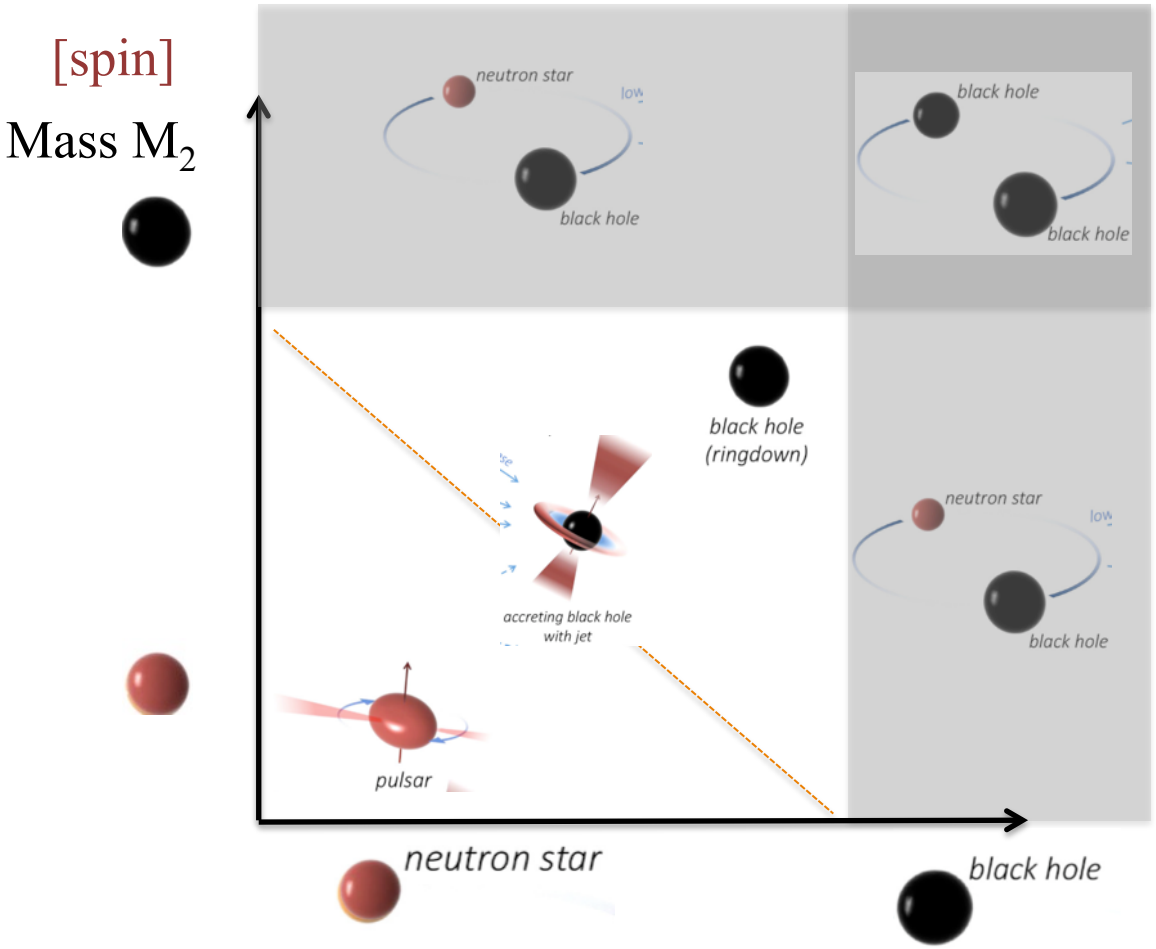
Mapping of “NS-NS”, “NS-BH” Merger Events

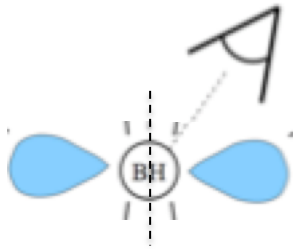


Mapping of "NS-NS", "NS-BH" Merger Events

GW ←→ GRB

time difference = 1.7 sec?





Observation

⊗ "θ_{obs}"

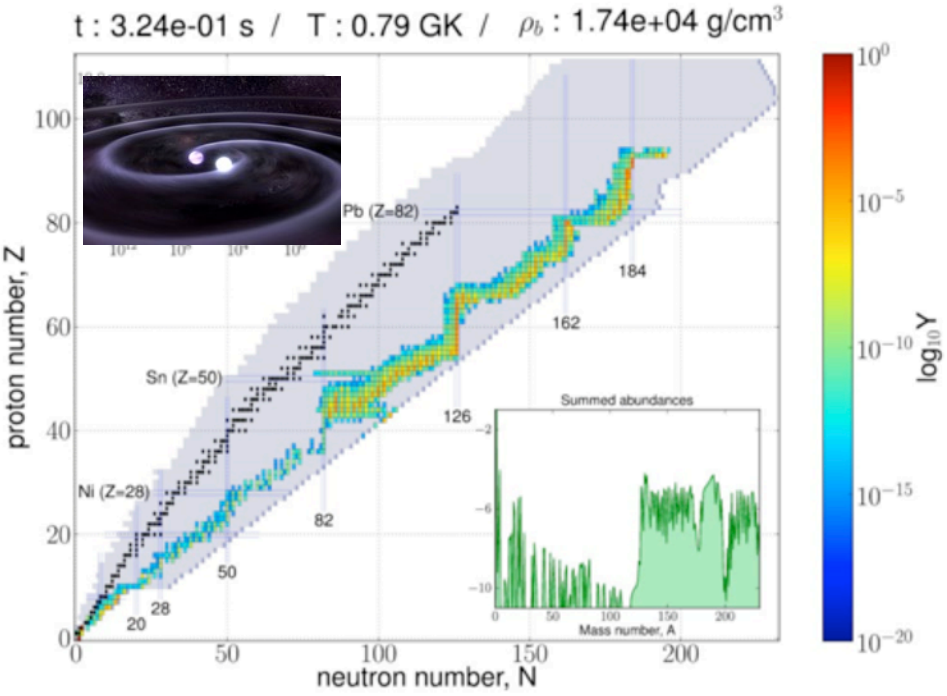
(as func. of time)

GW
Kilonova
GRB
: :

Nuclear Physics Inputs
EOS, Reactions,
Mass, Decay, …

Nucleosynthesis for dynamic ejecta

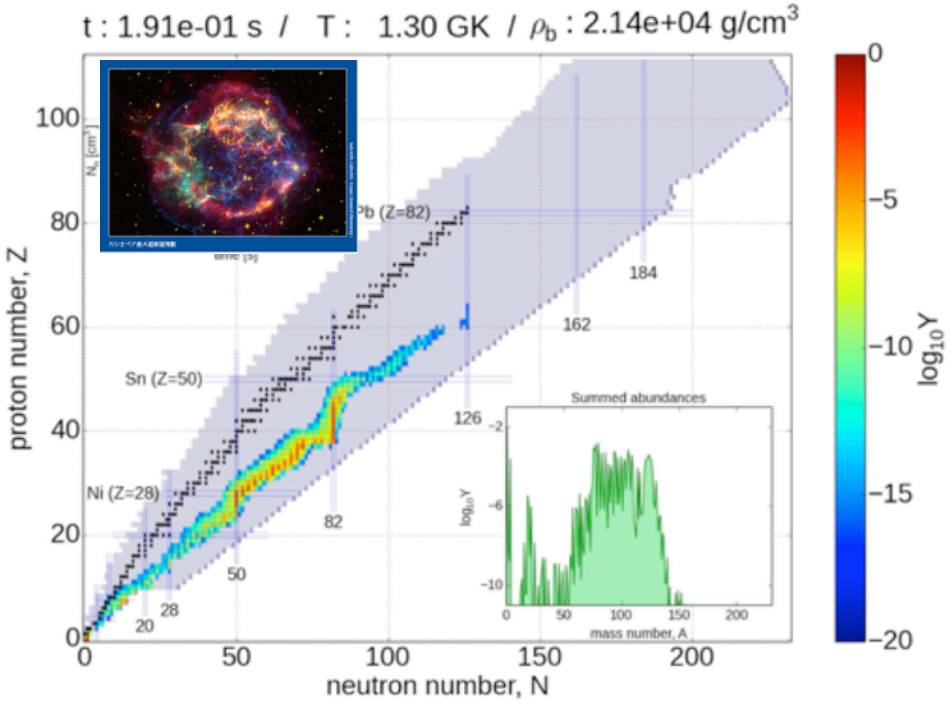
(snapshot; Korobkin et al. 2012)



- extremely neutron-rich (Ye ≈ 0.04)
- close to neutron drip-line
- extending to very large neutron (N≈ 200) and proton numbers (Z≈ 90)
- forging the heaviest elements (A>130) in the Universe (e.g. gold and platinum)

Nucleosynthesis for neutrino-driven winds

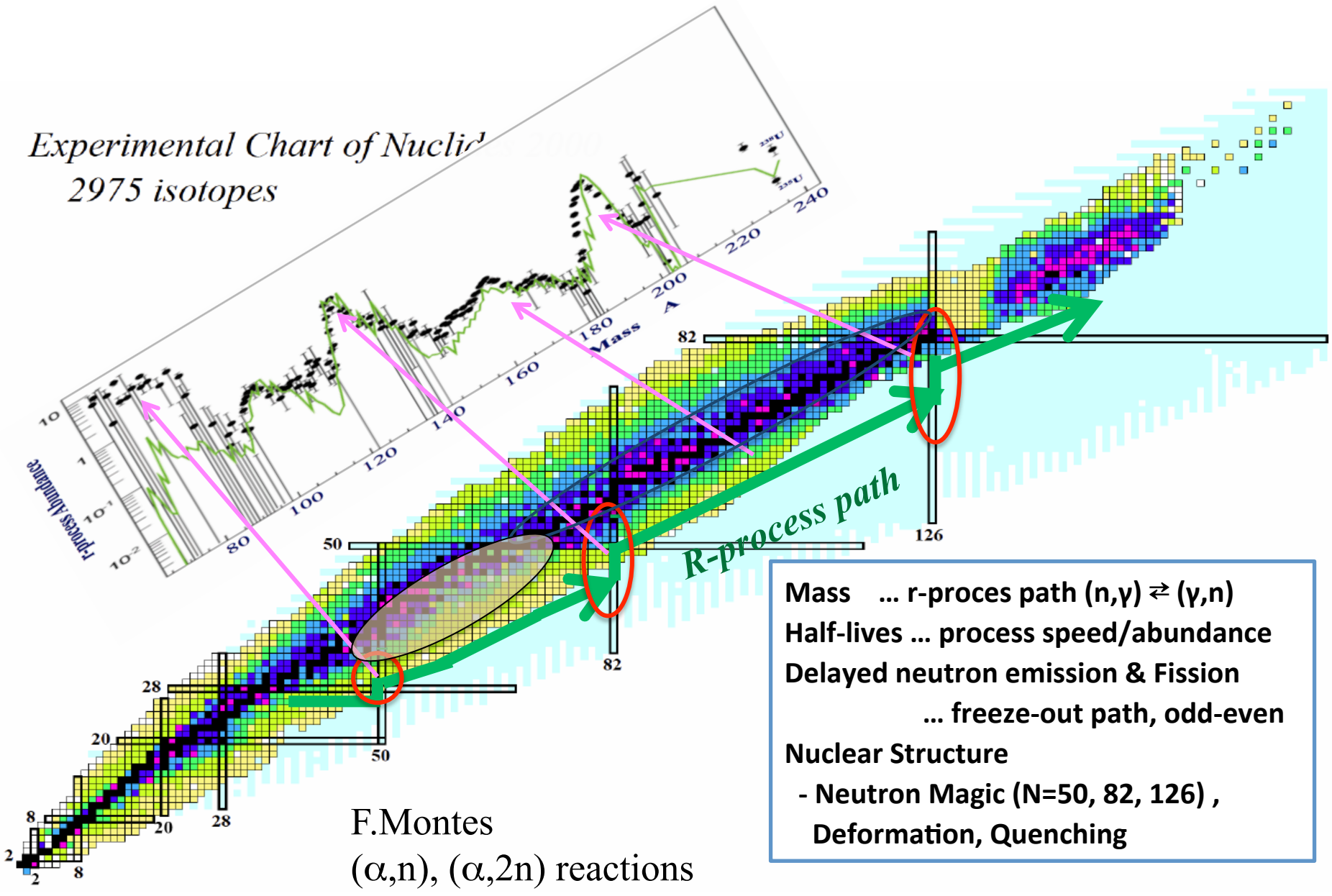
(snapshot; Martin et al. 2015)



- neutron-rich, broad distribution (0.2< Ye < 0.4)
- further away from neutron drip-line
- extending to moderately large neutron and proton number
- forging heavy elements, but usually with nucleon numbers A < 130

http://compact-merger.astro.su.se/Macronovae_04_2017.html

Nuclear Properties : Key Inputs for r process

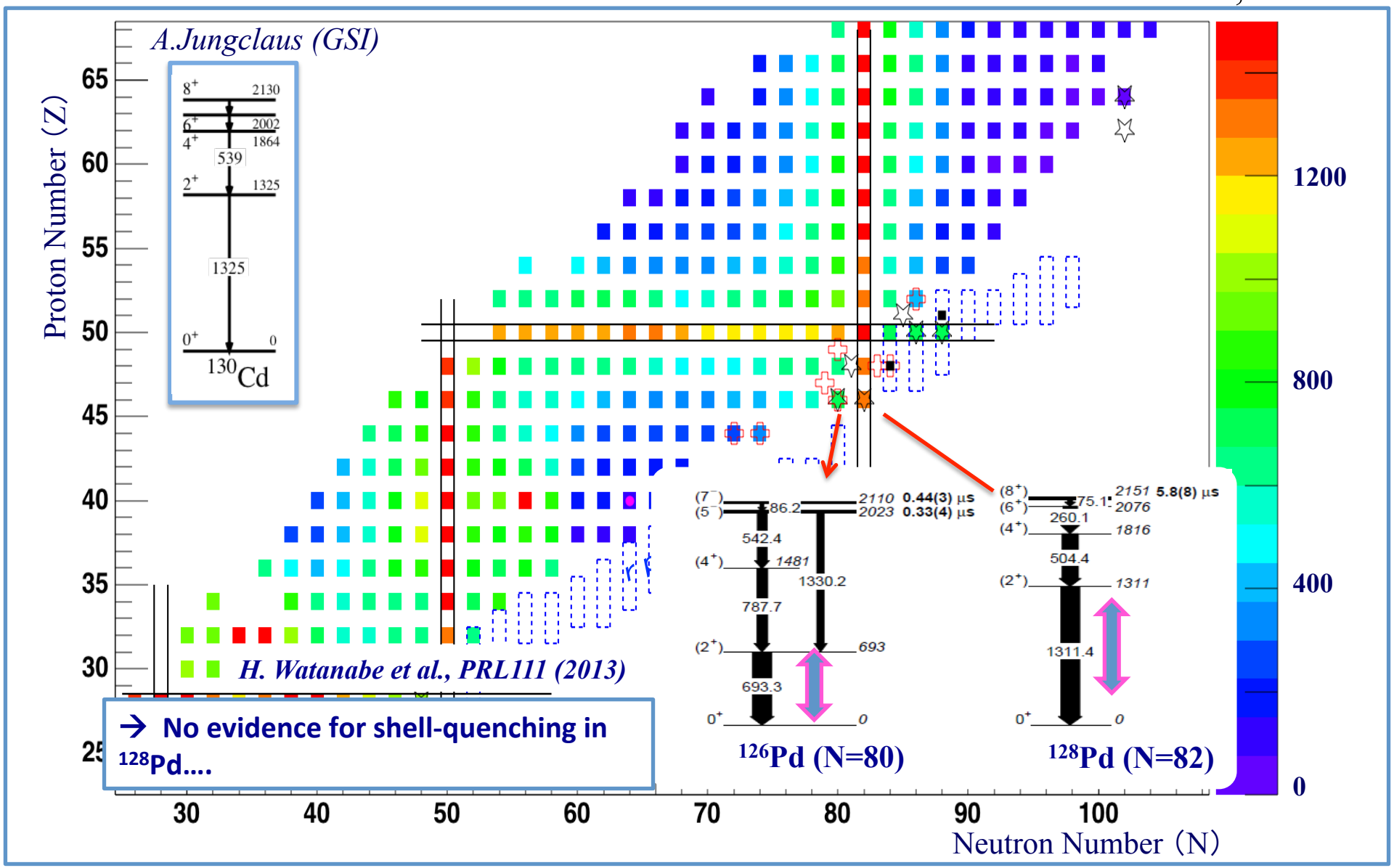


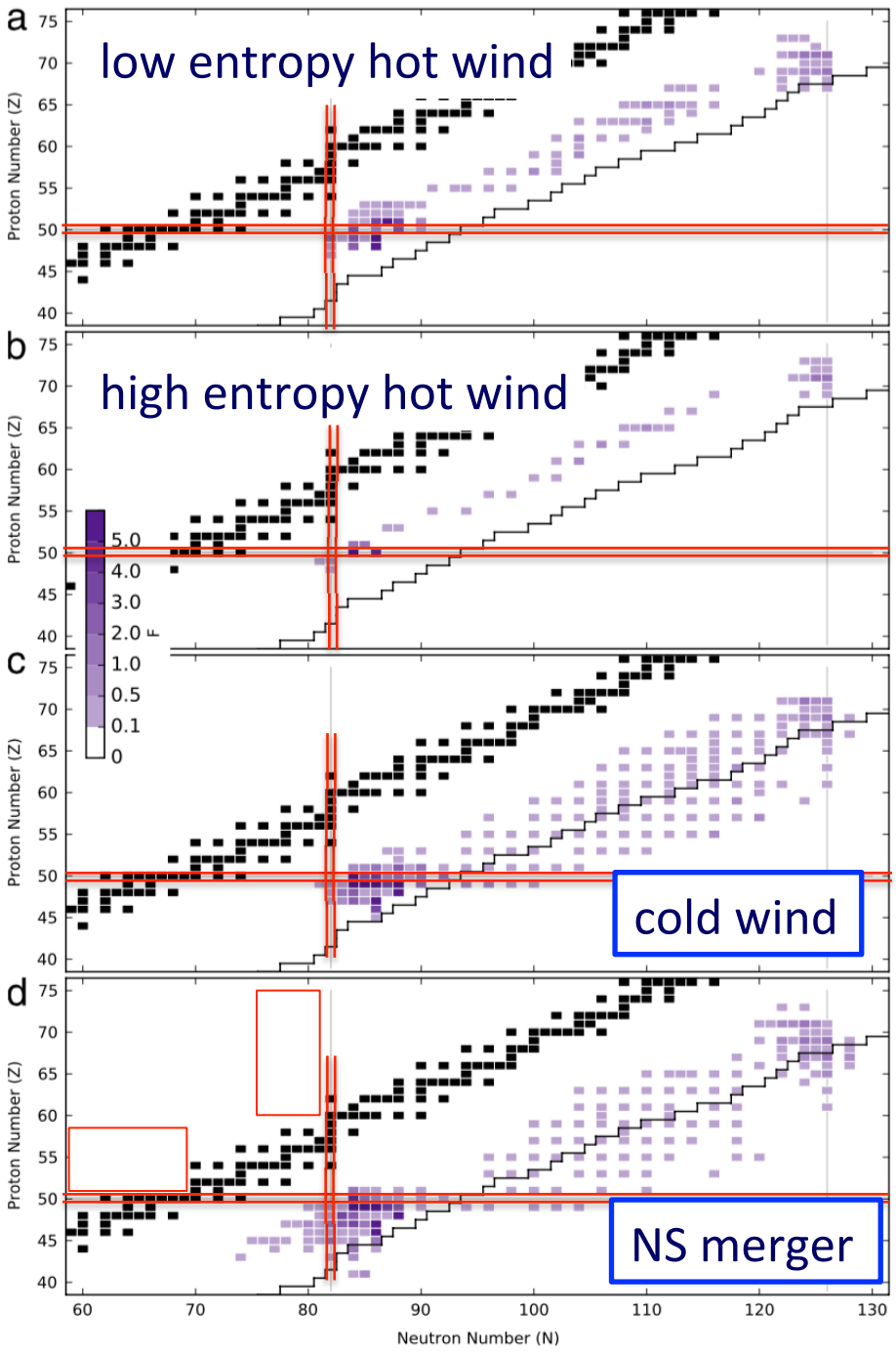
F.Montes
(α,n), (α,2n) reactions

Mass … r-proces path (n,γ) ⇄ (γ,n)
Half-lives … process speed/abundance
Delayed neutron emission & Fission
… freeze-out path, odd-even
Nuclear Structure
- Neutron Magic (N=50, 82, 126) ,
Deformation, Quenching

First Excited States E (2+)

Z: even, N:even





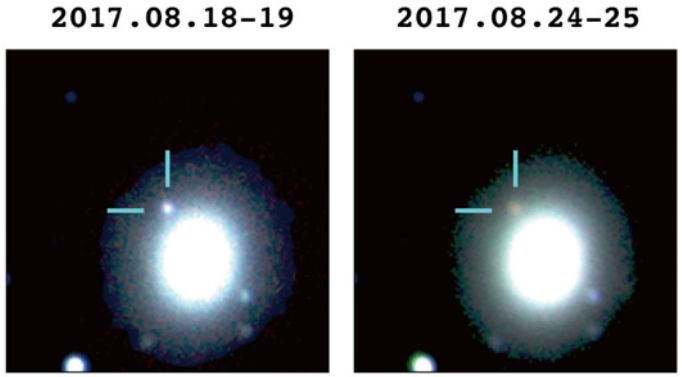
Pn values: How Sensitive in r-Process Calc.?

beta-delayed neutron emitters

M.R. Mumpower et al.
Prog. in Part. and Nucl. Phys
86 (2016) 86-126

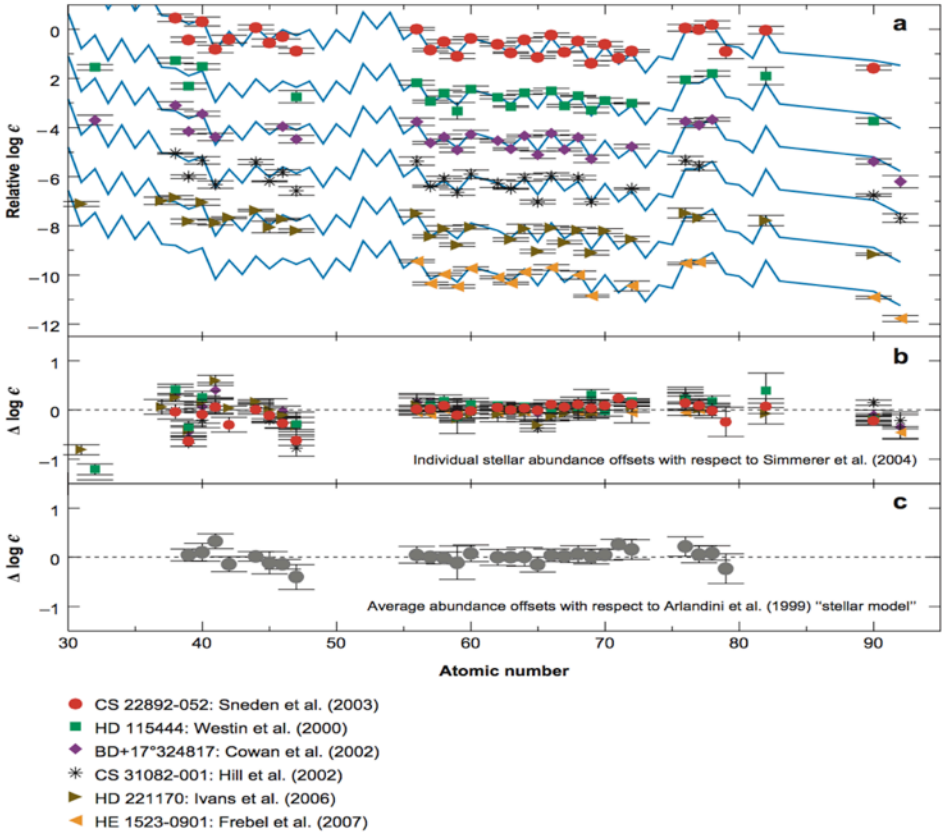
Is there evidence of Fission recycling ? [Gold, Uranium, etc..]

[GW170817]



Metal Poor Stars

C.Sneden etc.

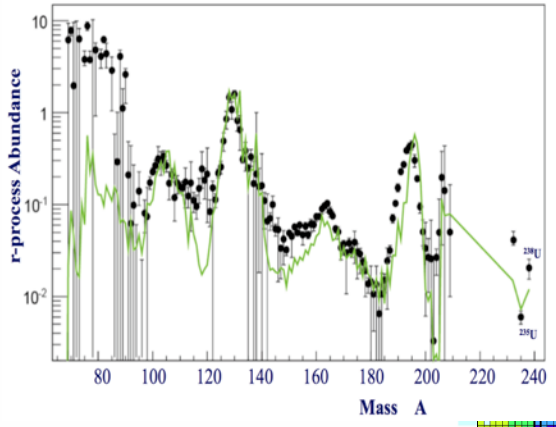


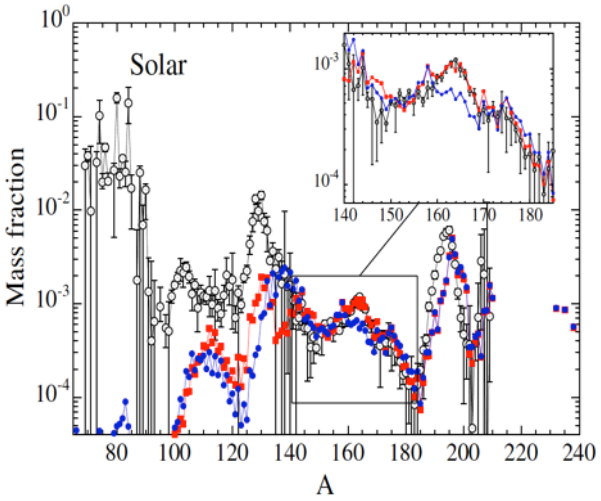
Rare-Earth Elements

Th(Z=90) vs Eu(Z=63) …. deviation !? (A.Frebel)

→ r-process condition?

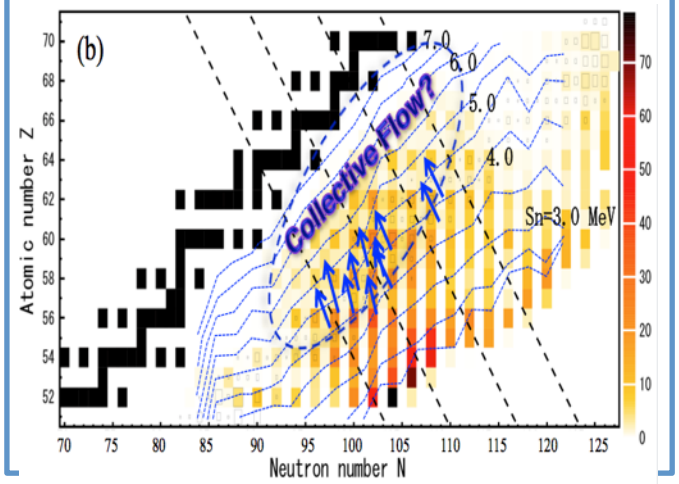
→ Cor





S. Goriely et al PRL 111, (2013)

R. Surman et al. PRL 79 (1997)

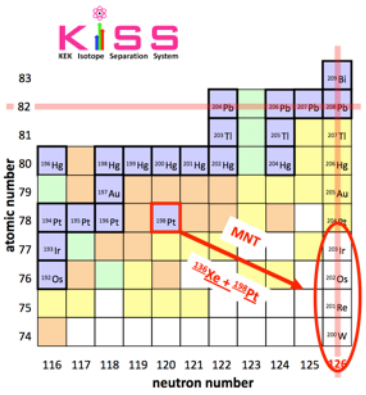


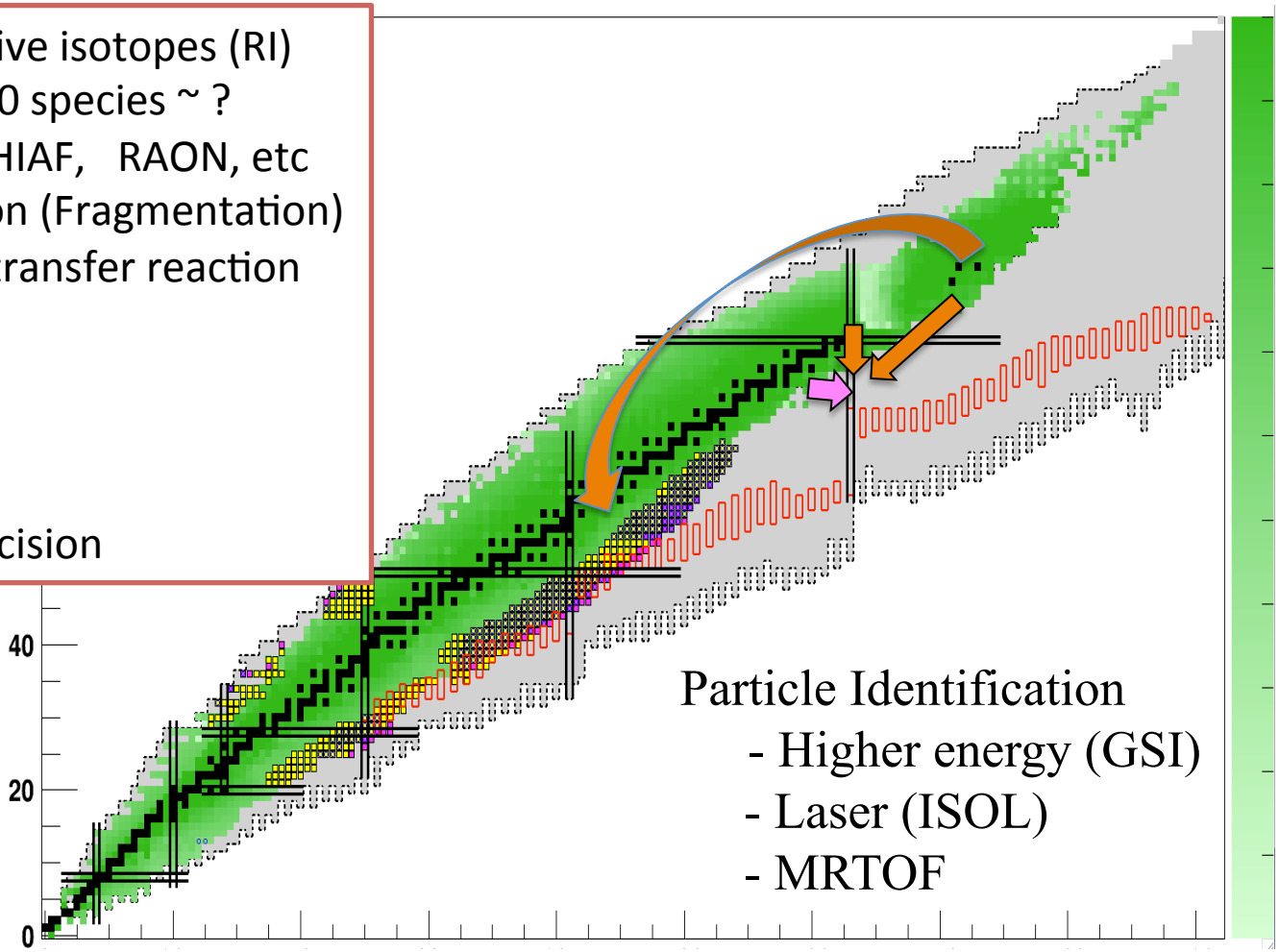
Question (1)

Which part of that nuclear physics data is already known, which part remains yet unmeasured, and which part will be accessible in the new RIB-facilities?

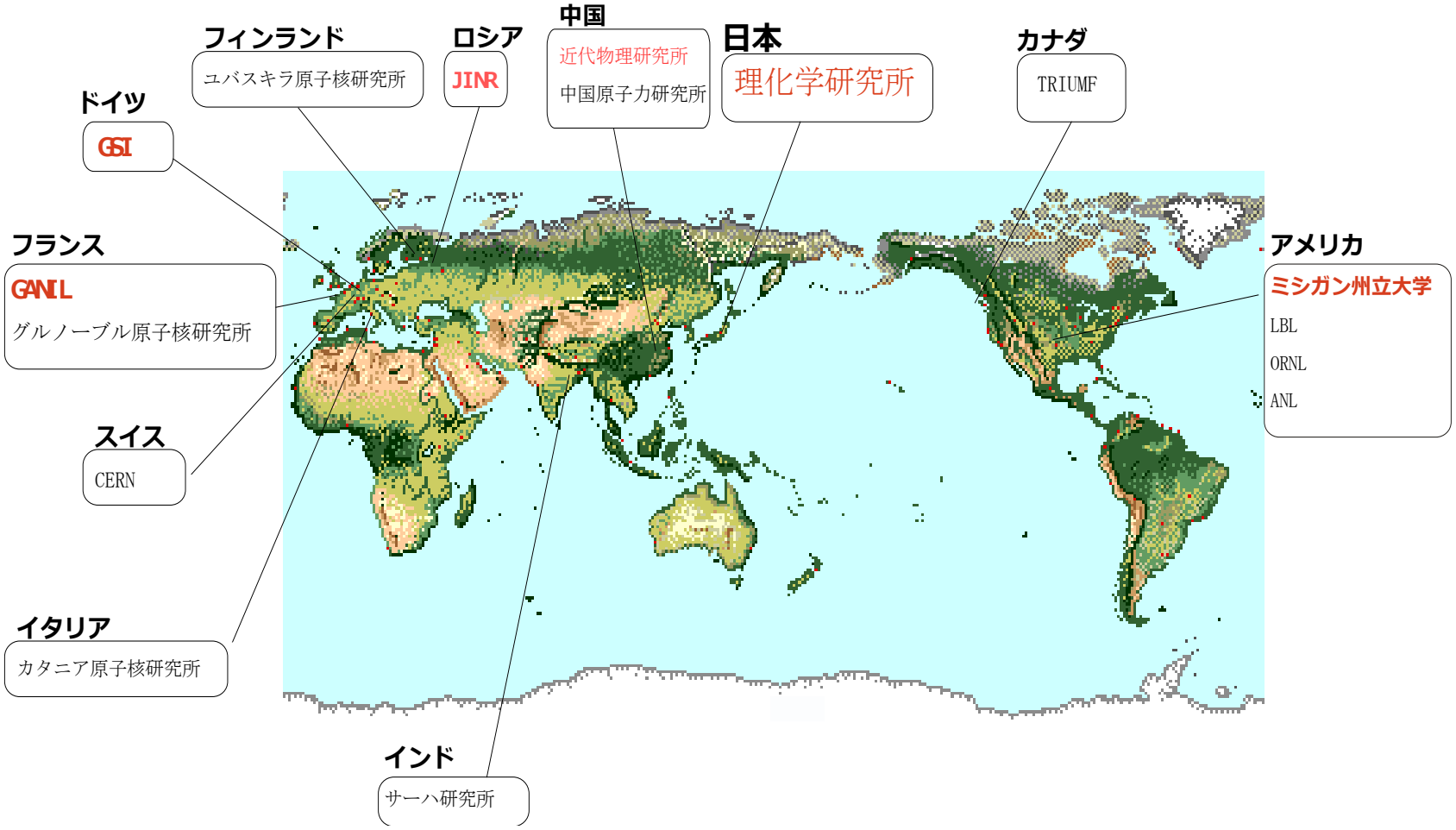
① Production of radioactive isotopes (RI)
- 3,000 species → 4,000 species ~ ?
- RIBF , FRIB, FAIR, HIAF, RAON, etc
  - U beam : Fission (Fragmentation)
  - Multi-nucleon transfer reaction

② Experiments
- Identification of RI
- Measurements
  - Low statistics
  - Accuracy & Precision





Red Color: Fragmentation method



GSI-FAIR(Germany) 2024 ? ~
FRIB (USA) 2022 ? ~

RISP (Korea) 2022? ~
HIAF (China) 202*? ~

Question to Next Generation RI Facilities

r-process	1st peak	2nd peak	Rare-earth	3rd peak	Fission
RIBF					
FAIR					
FRIB					

mass, T1/2, Pn, Tcal, Fission, excited states, reaction,

Some Slides

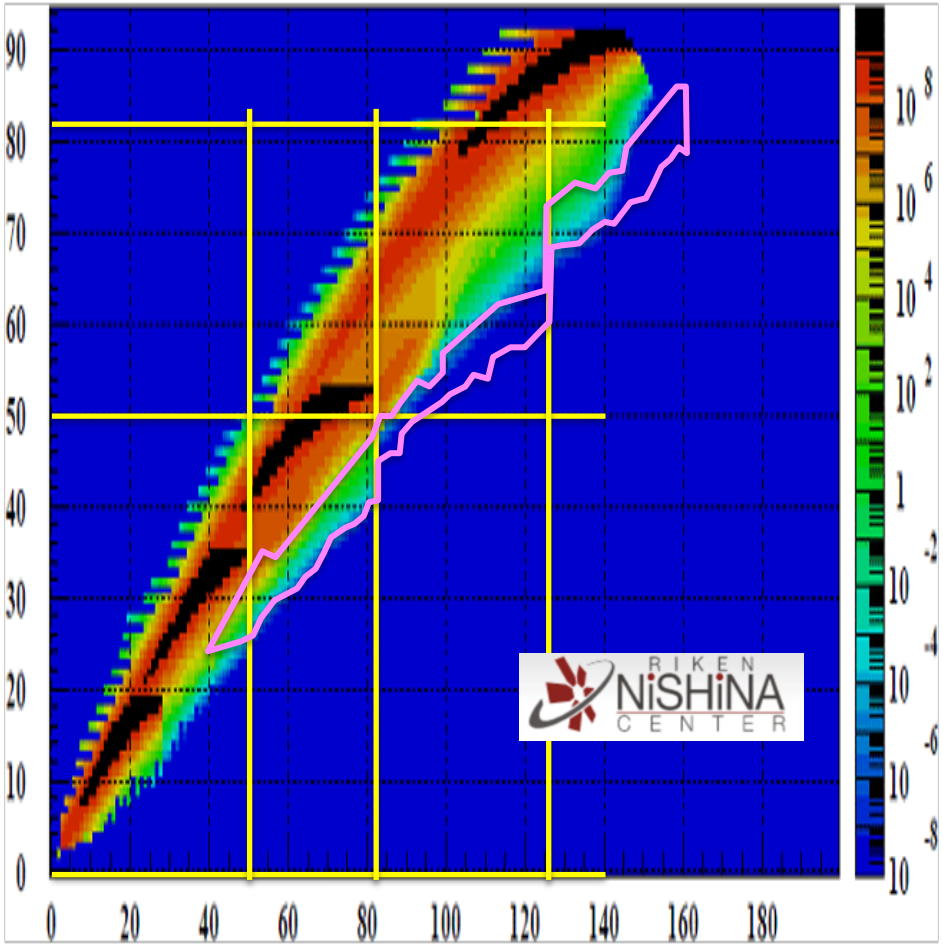
about

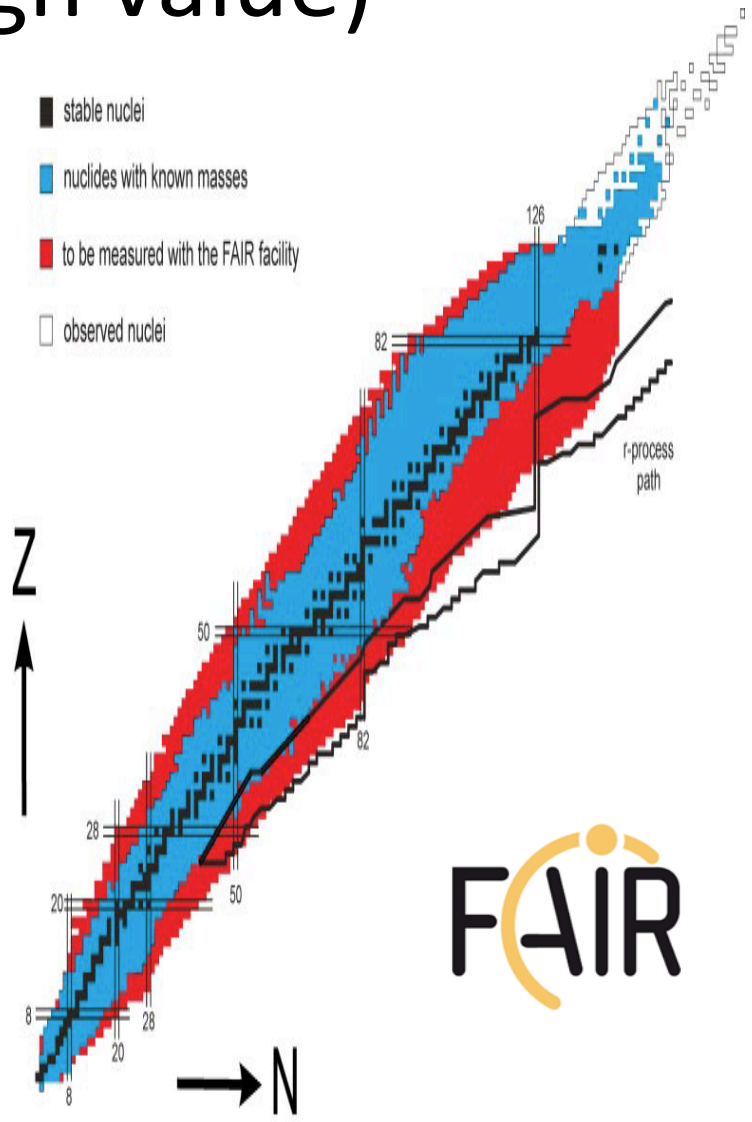
Future Experiments & Facilities

FRIB

RI Production (Design value)

RIBF (1000 pnA) … current int. = 60 pnA





Beam line transport should be taken into account

Questions

- **Are mergers the dominant source of heavy r-process elements?, Only source?**

- **Does AT 2017 gfo originates from the radioactive decay of r process nuclei?**

- **Will we ever know the exact composition?**

- **Can we identify particular nuclear signatures in the kilonova signal?**

- **Is there a particular "smoking gun" that points to the production of particular elements beyond the indirect inference of the production of lanthanides?**

- **What is the relevant nuclear physics for kilonova modeling?**

- **What will be the implications of observing a purely blue or purely red kilonova?**