FRLDM FISSION PROPERTIES FOR THE NUCLEOSYNTHESIS OCCURRING IN NEUTRON STAR MERGERS

Los Alamos NATIONAL LABORATORY EST. 1943

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FIRE Collaboration

Fission In R-process Elements

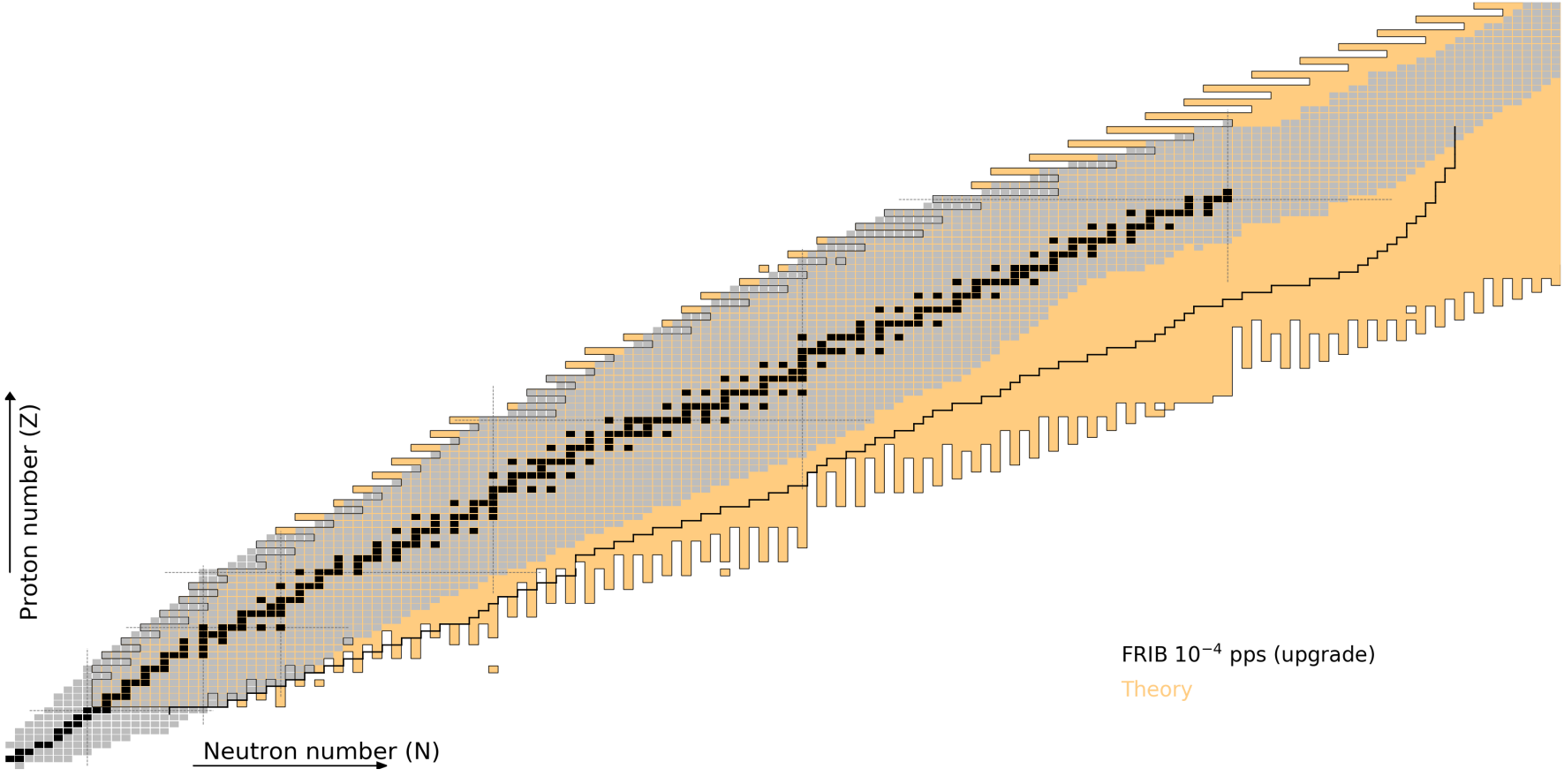
NUCLEAR PHYSICS AS THE LANGUAGE OF THE r-PROCESS

1st order: masses, β-decay rates, capture rates & fission

Dillmann *et al.* EPJA (2002) • Aprahamian ***et al.*** (2018) • See review paper: **Mumpower** *et al.* PPNP 86 (2016)

MUCH WILL BE MEASURED AT FRIB

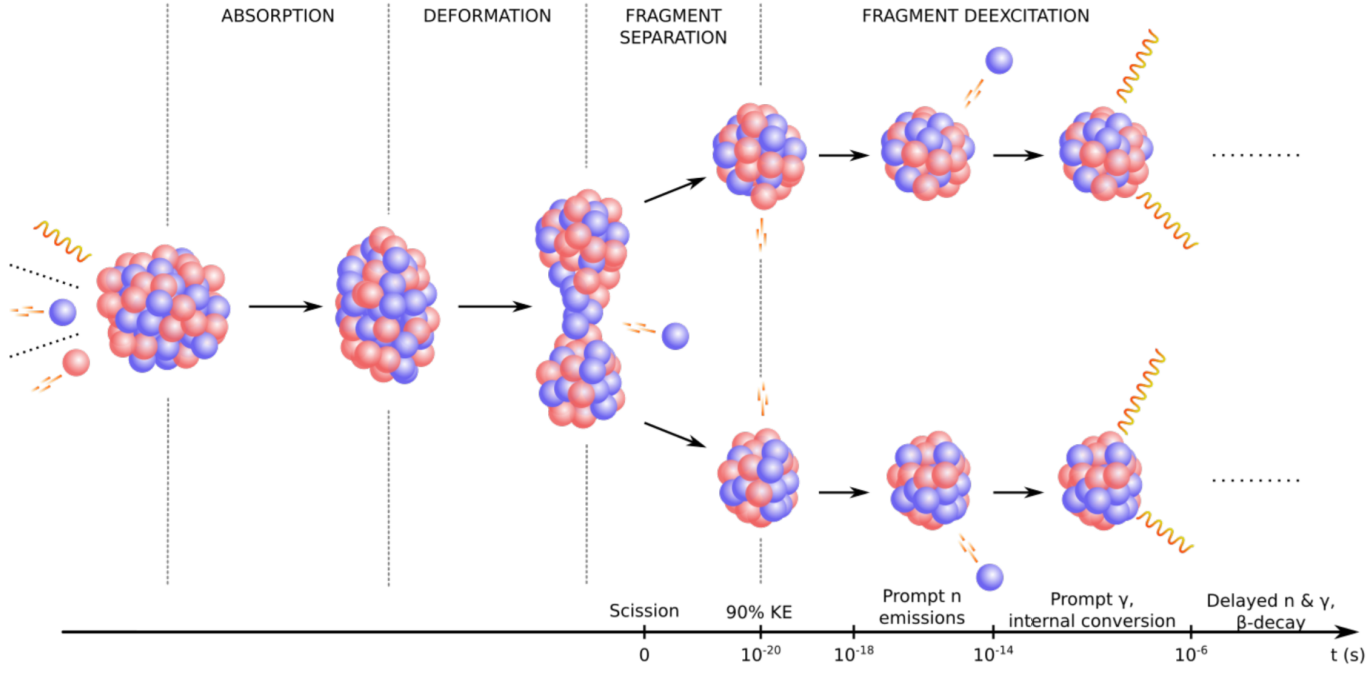
But fission studies will remain relatively inaccessible



∴ Fission theory is critical find any sort of "smoking gun" of heavy element production

Spyrou *et al.* PRL (2016) • Vilen *et al.* • PRL (2018) Orford *et al.* PRL (2018) • Sprouse *et al.* (2019) • Figure by **Mumpower**

NUCLEAR FISSION IN A NUTSHELL



The fission process:

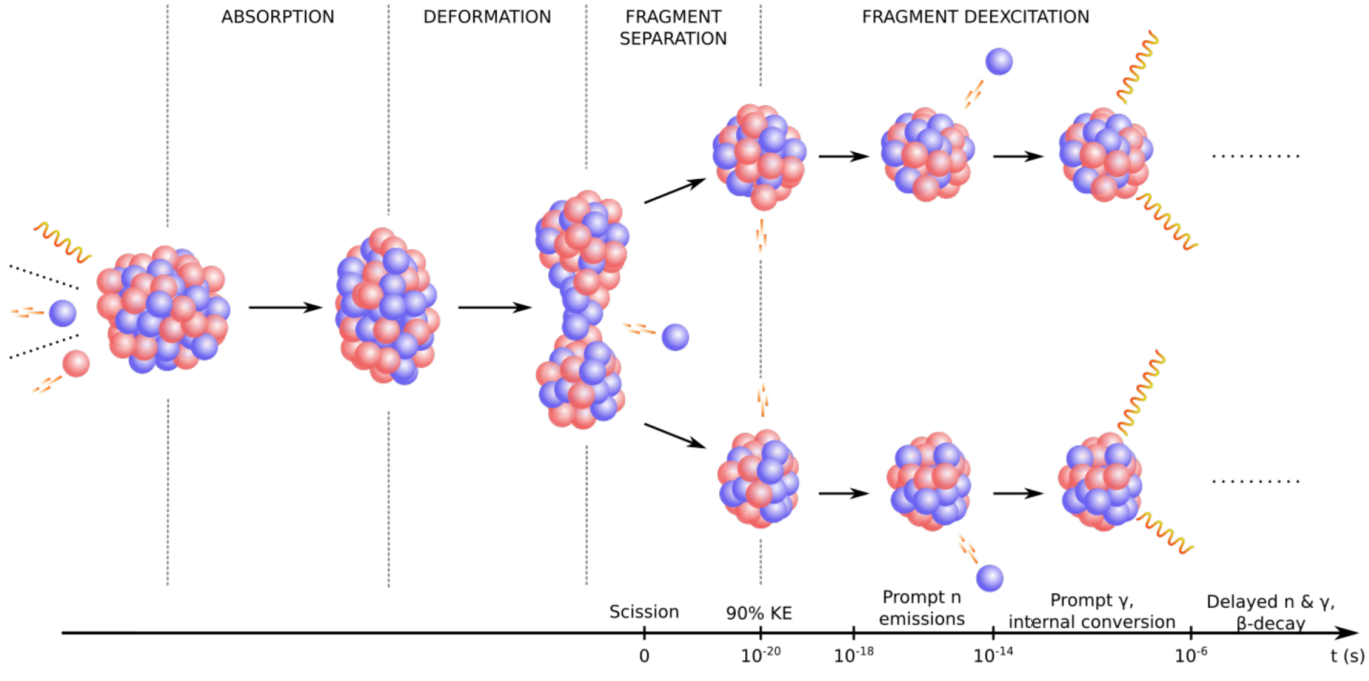
A heavy nucleus splits into two lighter fragments

Subsequent particle emission and decays then occur

Many events gives rise to fission yield

Meitner & Frisch (1938) • Bohr & Wheeler (1939) • Figure from Verriere & **Mumpower** in prep. (2019)

NUCLEAR FISSION FOR THE r-PROCESS



Influence on the r-process:

Fission rates and branching determine re-cycling (robustness)

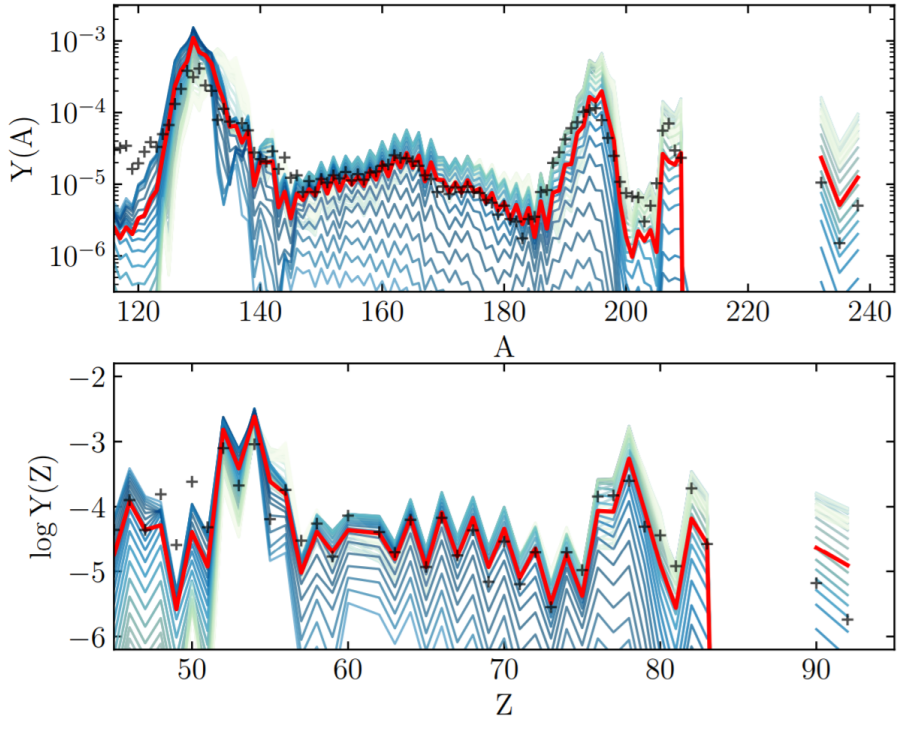
Fragment yields place material at lower mass number; barriers determine hot spots

Large Q-value ⇒ impacts thermalization and therefore possibly observations

Responsible for what is left in the heavy mass region when nucleosynthesis is complete ⇒ "smoking gun"

Holmbeck ***et al.*** ApJ 870 1 (2019) • Vassh ***et al.*** J. Phys. G (2019) • Figure from Verriere & **Mumpower** in prep. (2019)

LONG-LIVED ACTINIDES



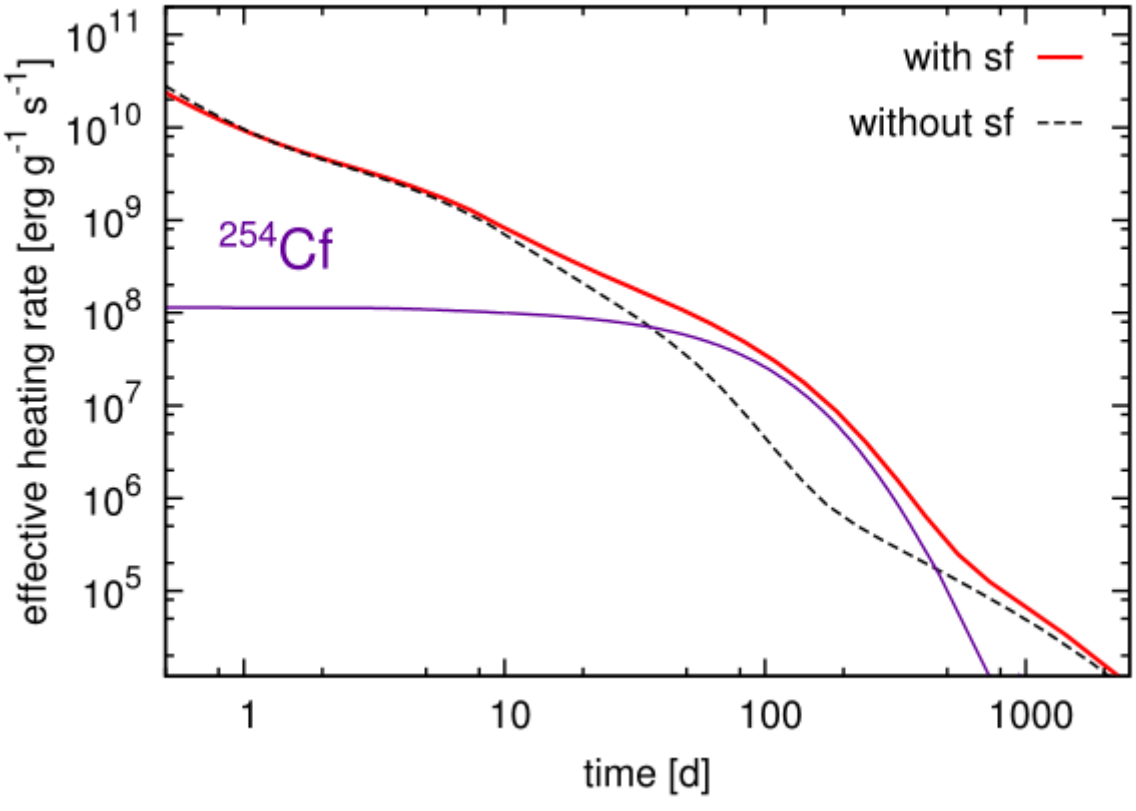
Recent calculations show: if actinides are produced, they are usually overproduced versus lanthanides

A sufficient amount of dilution with lighter r-process material is required to match the solar isotopic residuals

∴ Fission theory can also inform us on galactic chemical evolution

Côté ***et al.*** ApJ (2018) • Holmbeck ***et al.*** ApJ 870 1 (2019) • Vassh ***et al.*** J. Phys. G (2019) • Holmbeck ***et al.*** submitted (2019)

ONE EXAMPLE: ^{254}CF(Z=98)



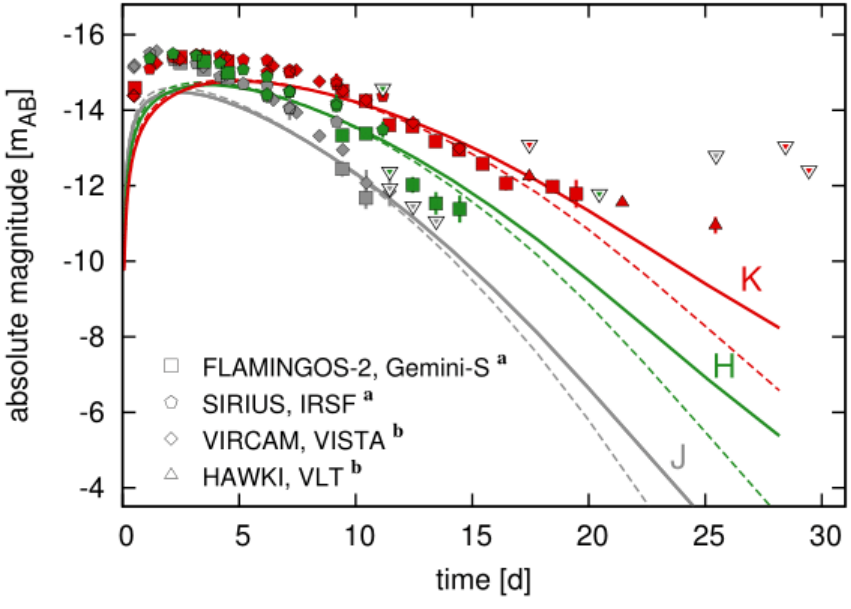
Is there any possible precursor to show that actinide nucleosynthesis has occurred in an event?... Maybe!

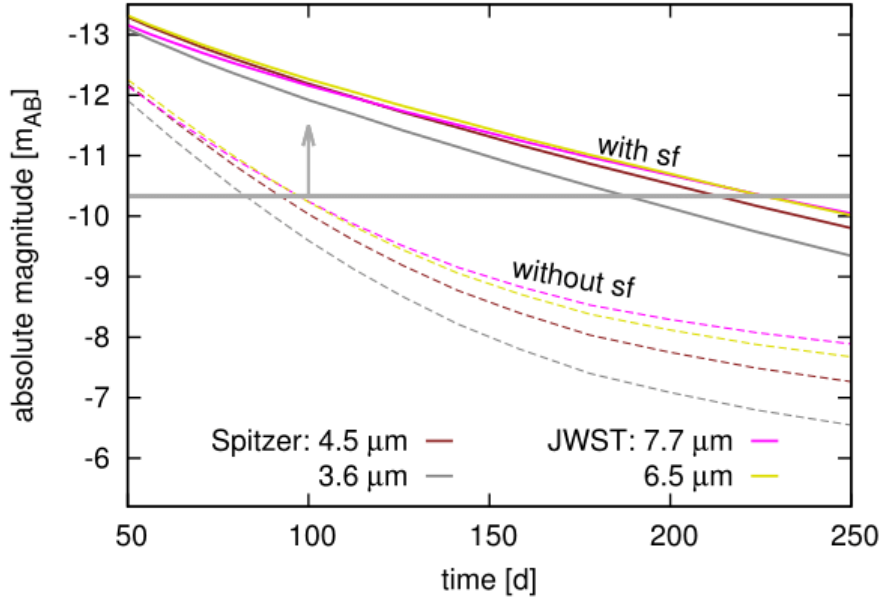
The spontaneous fission of ^{254}Cf can be a *primary* contributor to nuclear heating at late-time epochs

The $T_{1/2} \sim 60$ days; found from nuclear weapons testing

Baade *et al.* PASP (1956) • Conway *et al.* JOSA (1962) • Y. Zhu ***et al.*** ApJL 863 2 (2018) • Vassh ***et al.*** J. Phys. G (2019)

OBSERVATIONAL IMPACT OF CALIFORNIUM





Both near- and middle- IR are impacted by the presence of ^{254}Cf

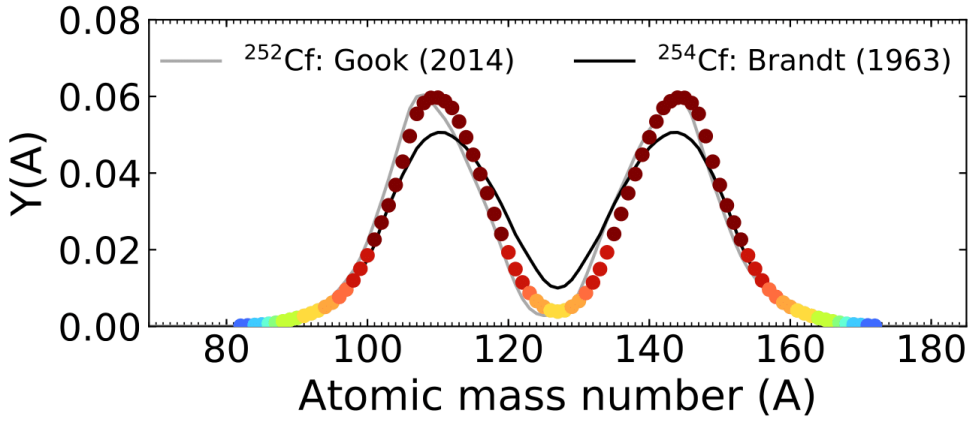
Late-time epoch brightness can be used as a proxy for actinide nucleosynthesis

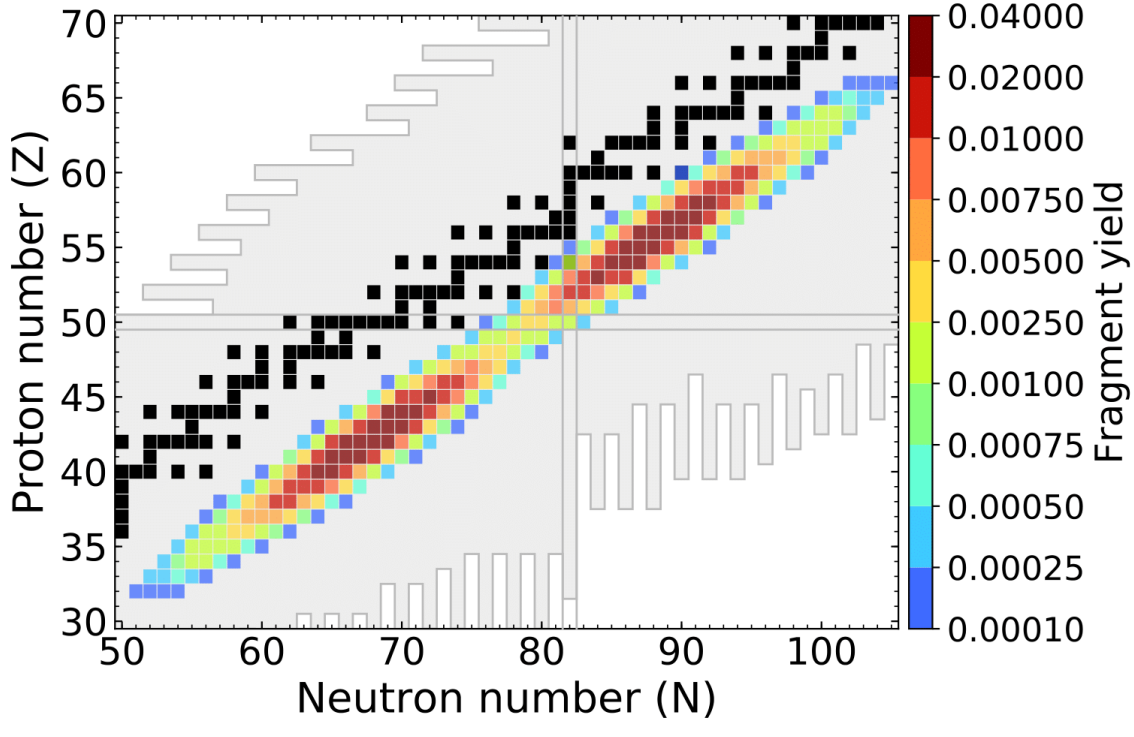
Future JWST will be detectable out to 250 days with the presence of ^{254}Cf

This also has implications for merger morphology...

Y. Zhu ***et al.*** ApJL 863 2 (2018) • Miller ***et al.*** in prep (2019) • Korobkin ***et al.*** in prep (2019)

CALCULATED YIELD (CALIFORNIUM)





Jaffke *et al.* PRC 67 034608 (2018) • Y. Zhu ***et al.*** ApJL 863 2 (2018) • **Mumpower** *et al.* in prep. (2019)

SPECIAL THANKS TO

My collaborators

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& **many more**...

▣ Students ▣ Postdocs ▣ FIRE PI ▣ LANL

SUMMARY

The r-process relies on fission in many ways:

Re-cycling material ▲ Actinide production ▲ Late-time observations

FRIB and other facilities will make a lot of measurements, but fission studies remain relatively inaccessible

Fission theory is crucial to understanding the formation of the heaviest elements (and $A \sim 130$)

The FIRE Collaboration will soon provide a suite of new fission properties for the community:

Rates • Branchings • Yields • Q-values • Spectra

Results / Data / Papers @ MatthewMumpower.com