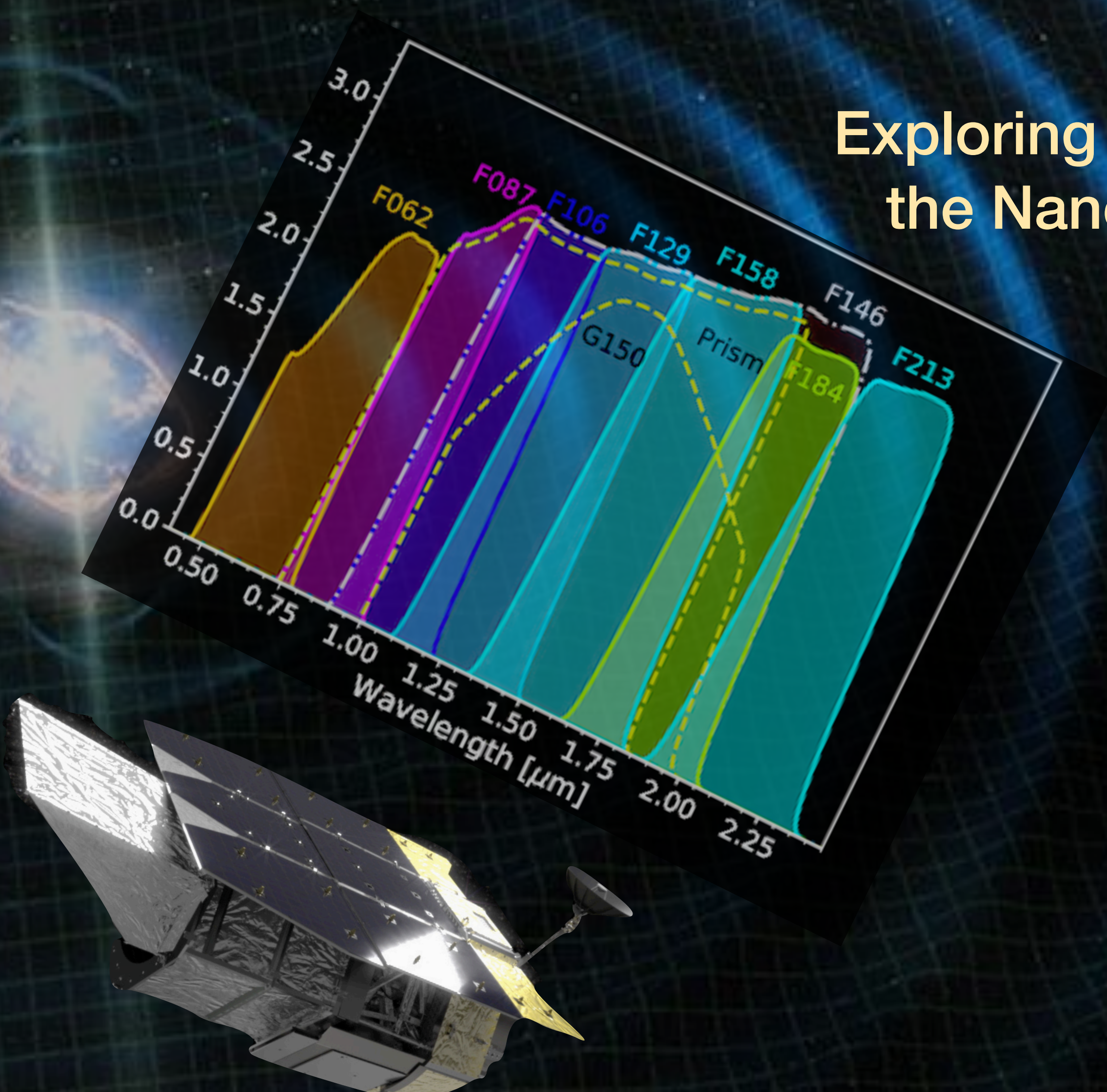
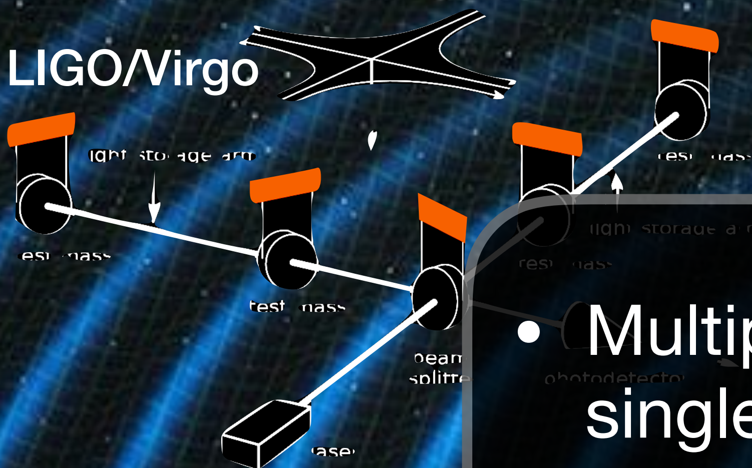
Multi-messenger Astronomy with the Roman Space Telescope

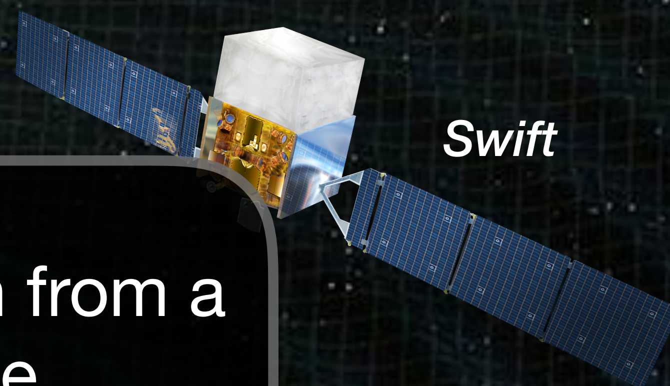


Exploring the Transient Universe with the Nancy Grace Roman Telescope
Feb 9, 2022

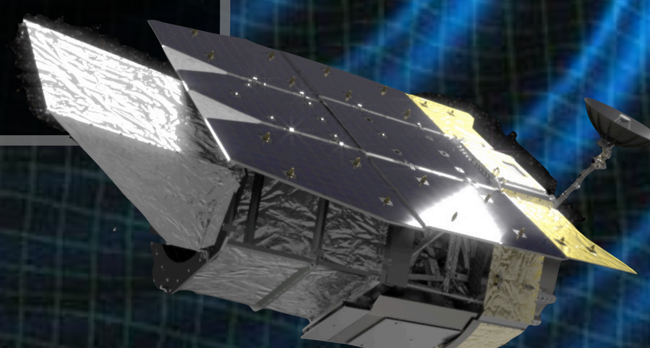
Jennifer Barnes
KITP, UC Santa Barbara

Multi-messenger astronomy defined

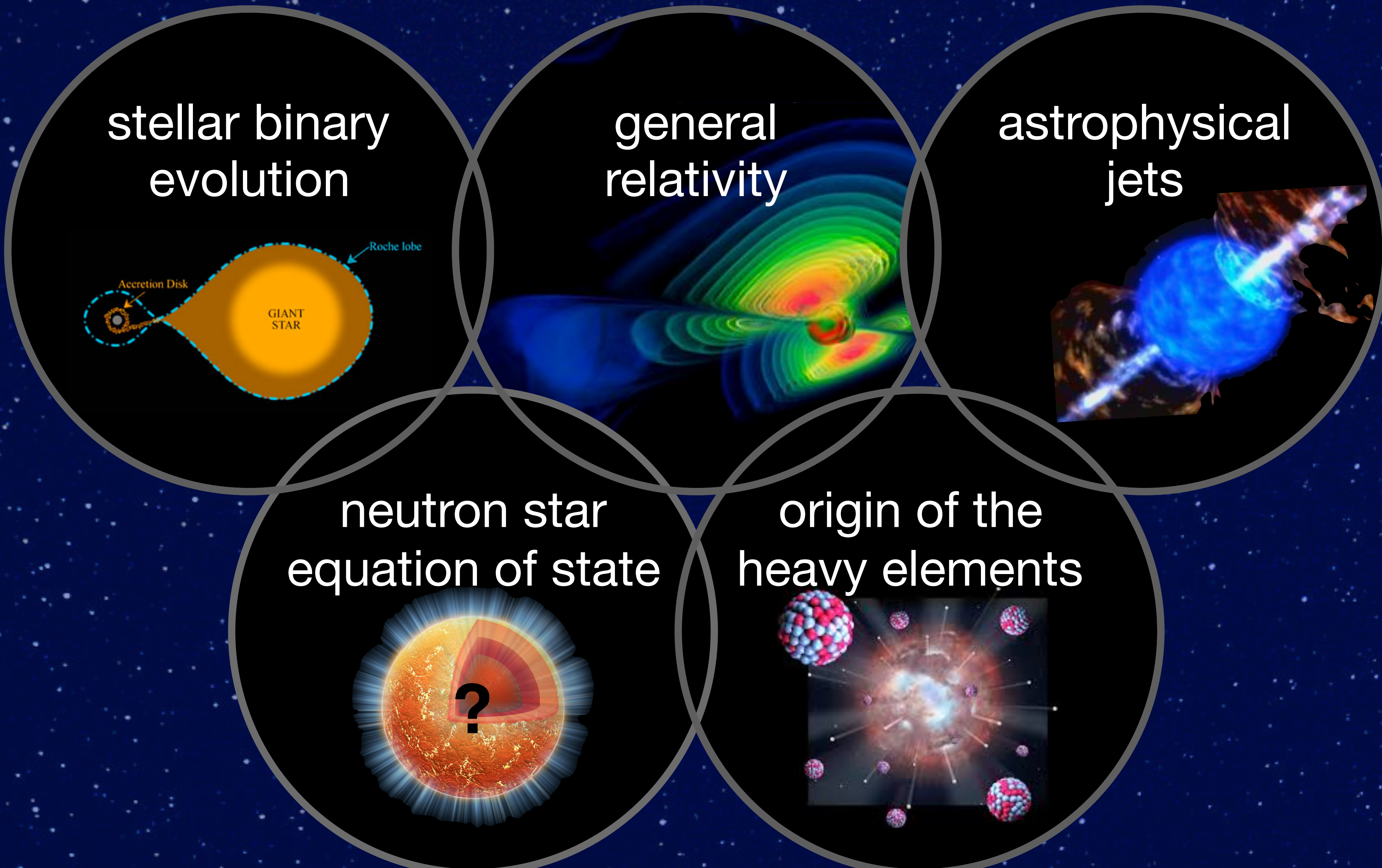




- Multiple types of emission from a single astrophysical source
  - Gravitational waves (GW)
  - Electromagnetic radiation (EM)
  - Neutrinos
- Focus today: binary neutron star and neutron star-black hole mergers

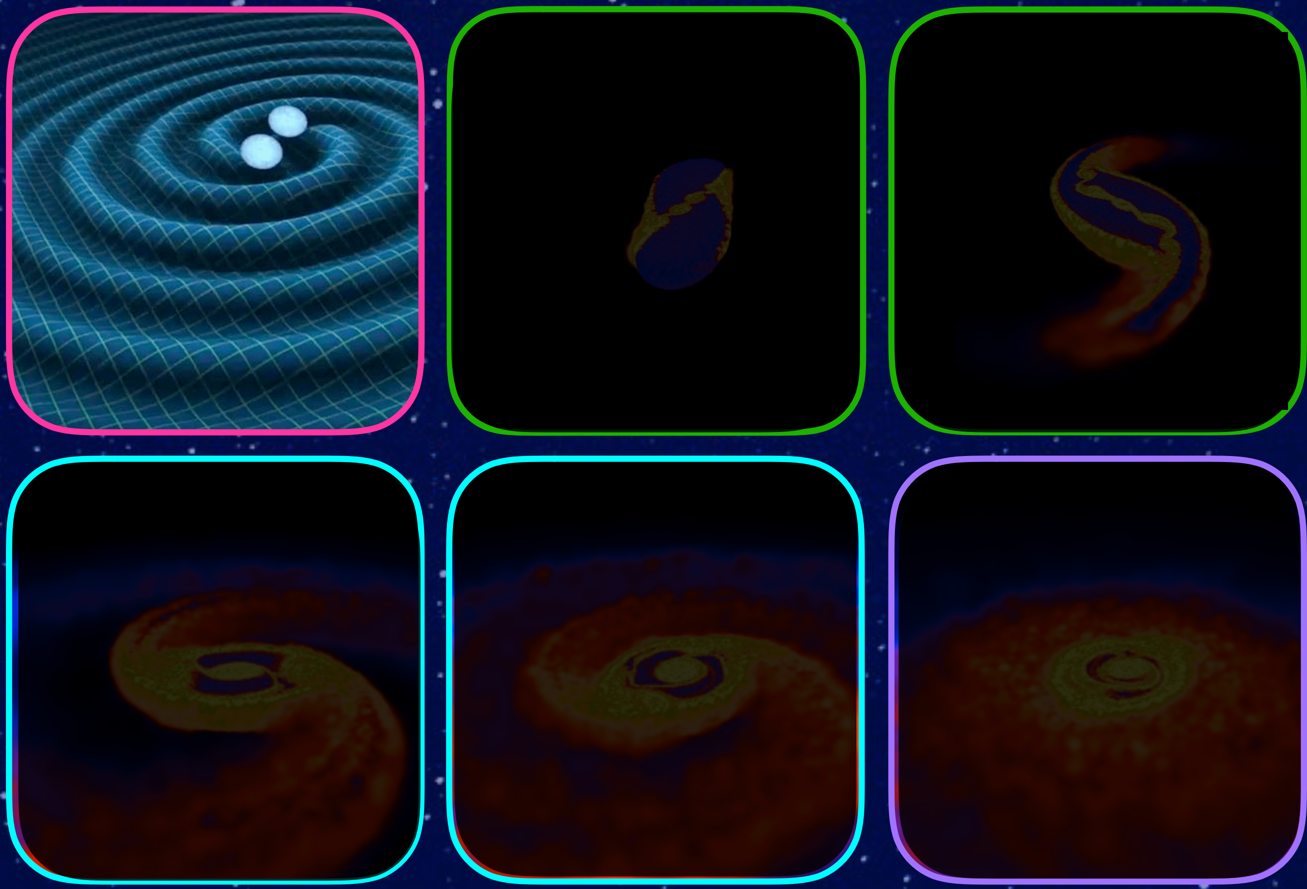


Compact object mergers overlap with many important questions



Compact object mergers are a stellar danse macabre

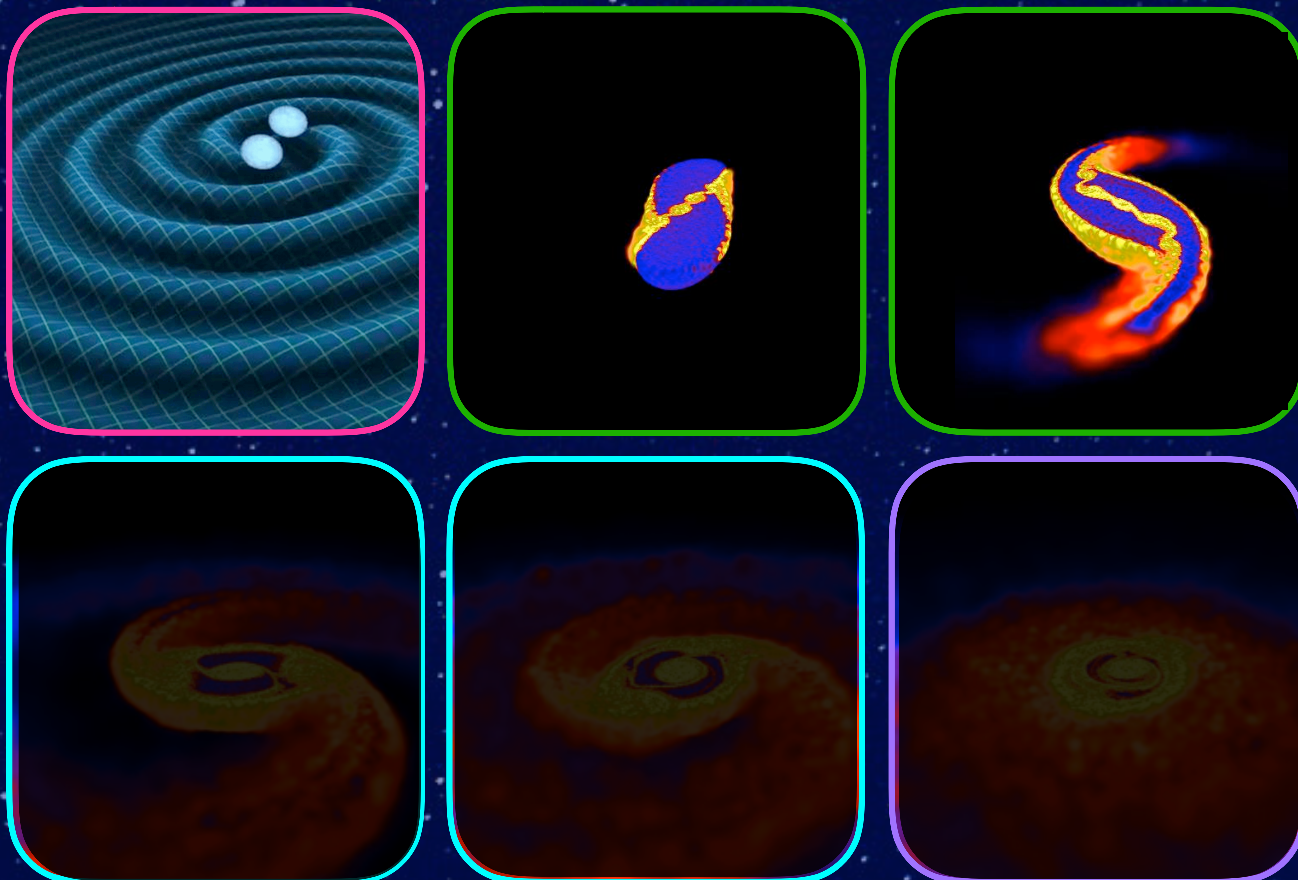
final orbits:
strong GW source



Compact object mergers are a stellar danse macabre

final orbits: strong GW source

merger: neutron star disrupts, central remnant forms



Compact object mergers are a stellar danse macabre

final orbits: strong GW source

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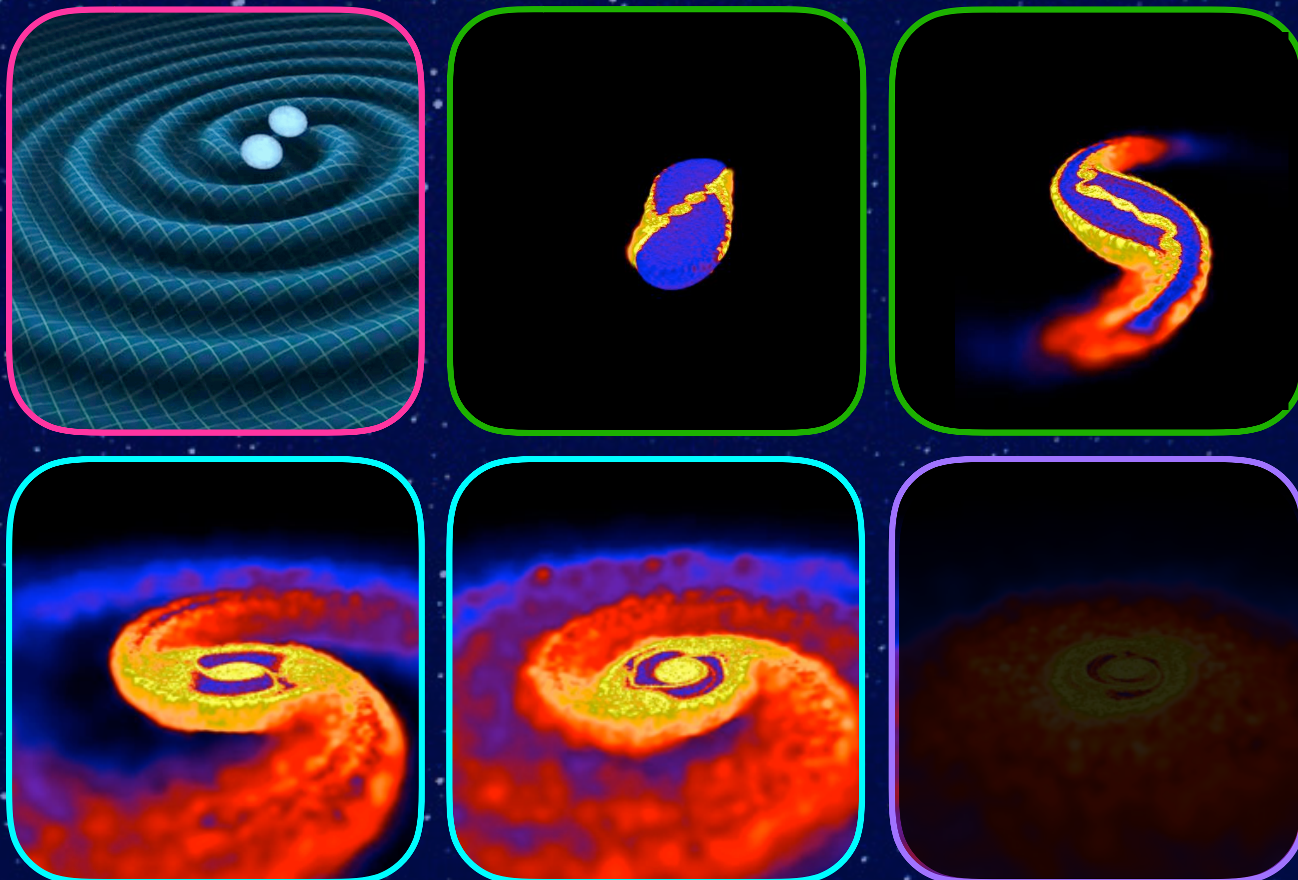
ejecta: some material escapes; some is bound



Compact object mergers are a stellar danse macabre

final orbits: strong GW source

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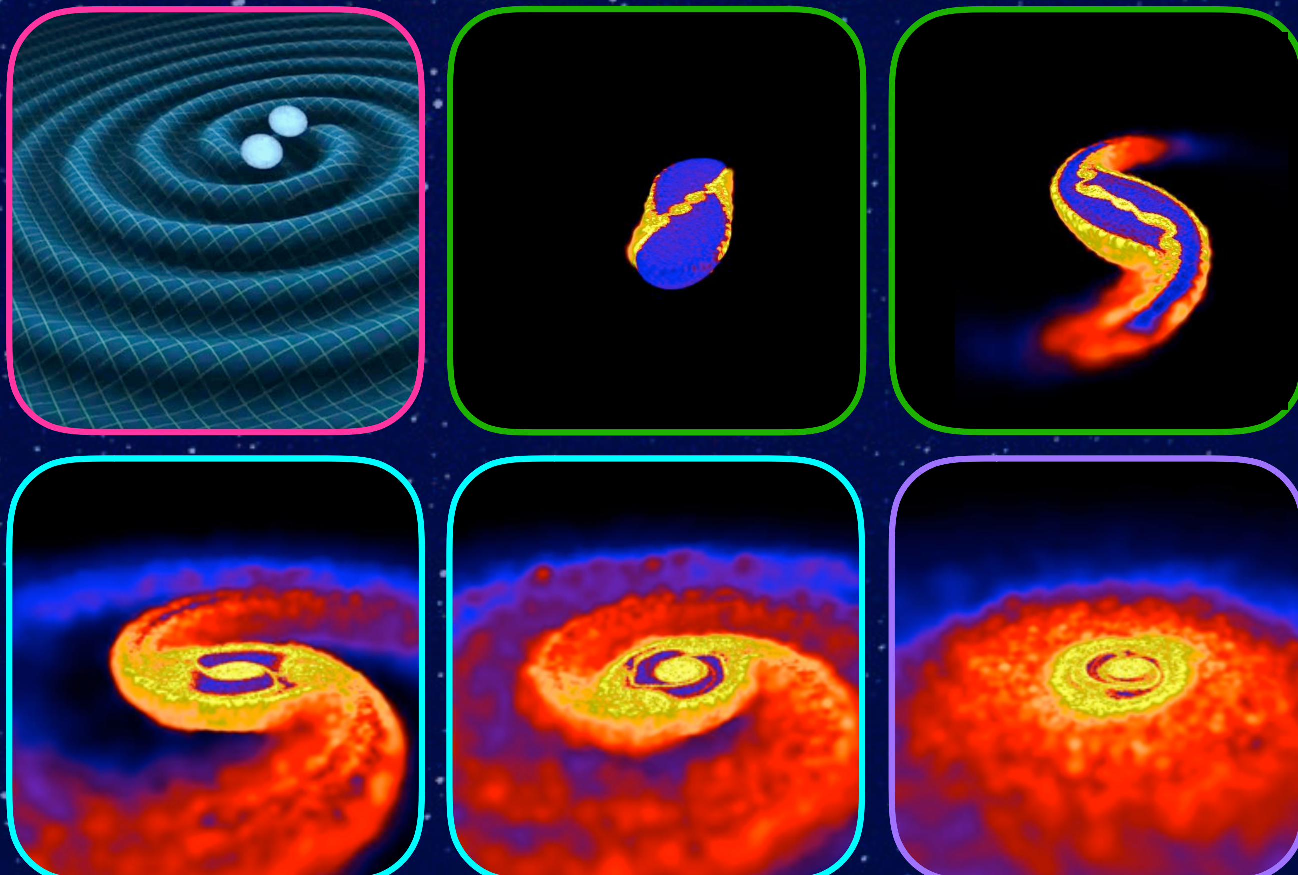
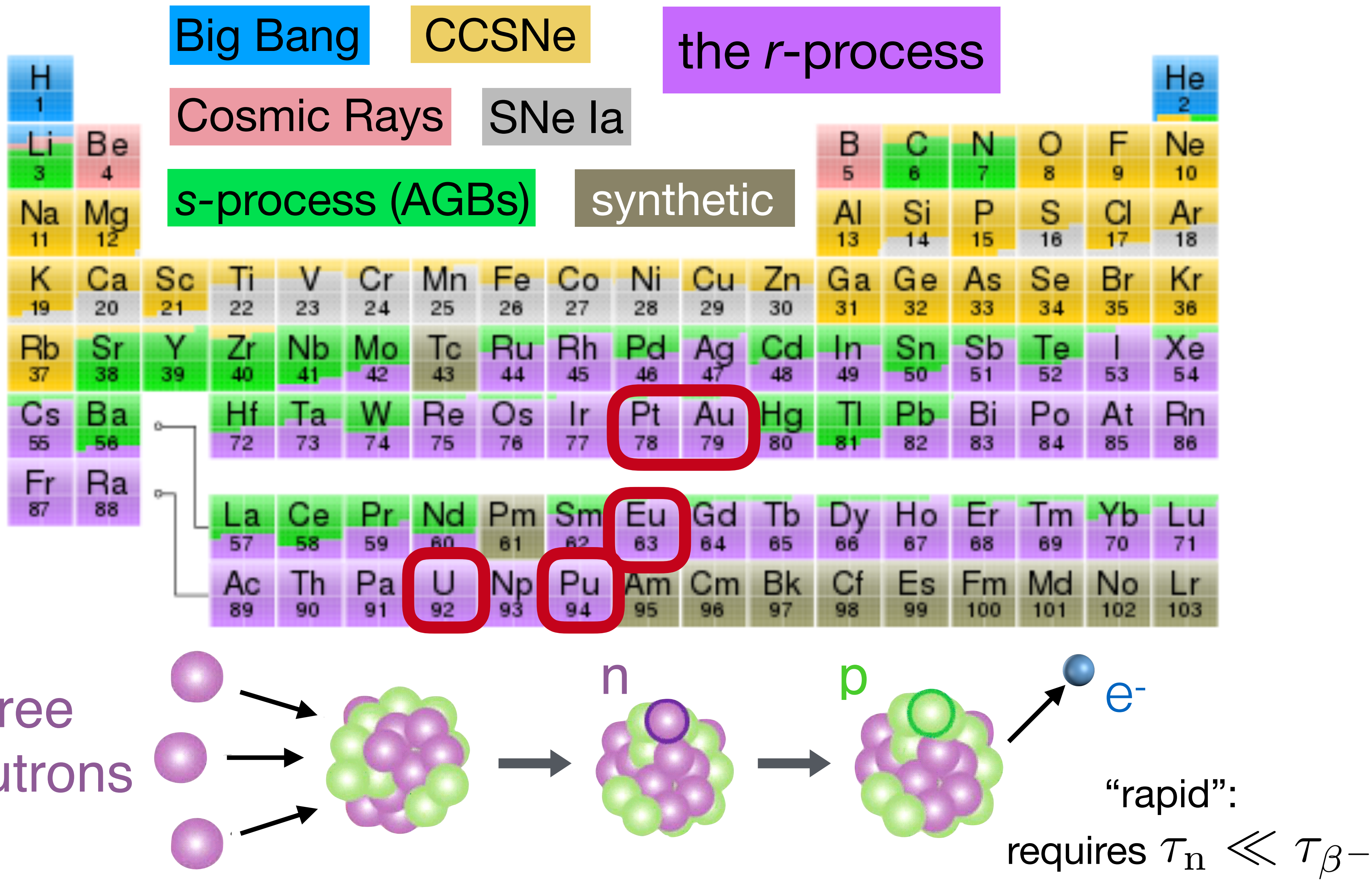


ejecta: some material escapes; some is bound

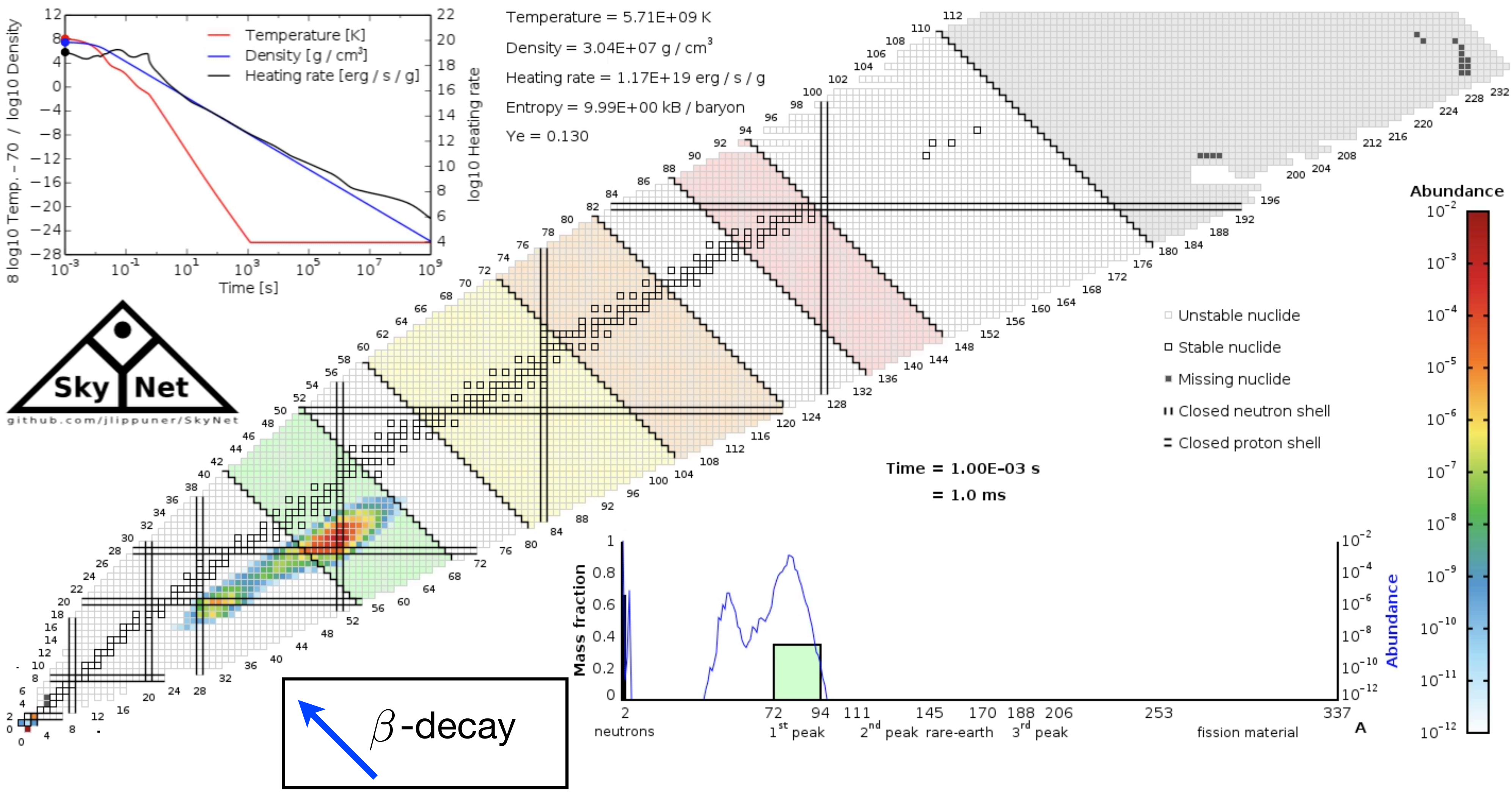
final: a central NS or BH, an accretion disk, unbound ejecta

The *r*-process produces ~half of elements heavier than Fe



The *r*-process produces ~half of elements heavier than Fe

courtesy J. Lippuner

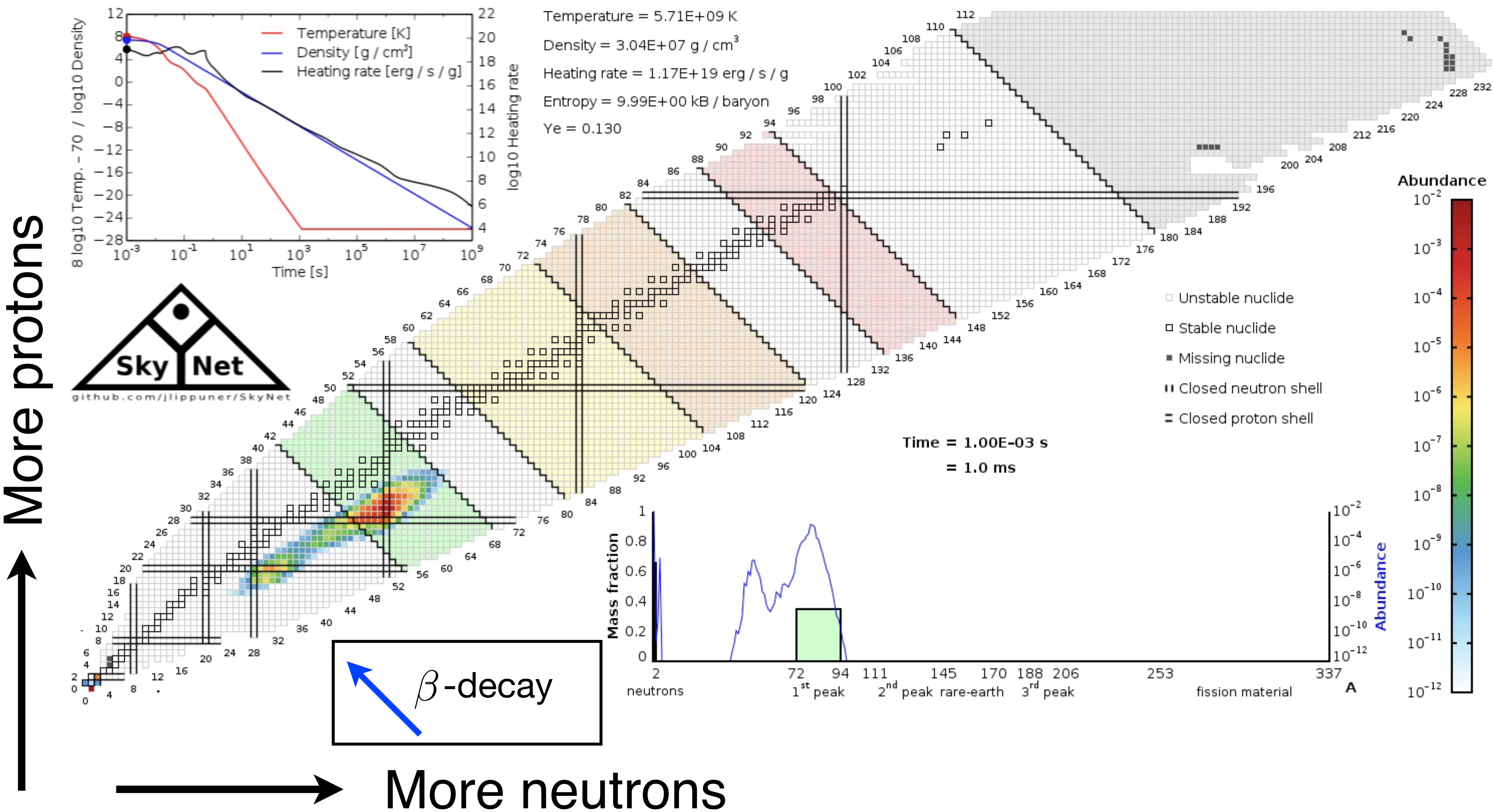


More protons

More neutrons

The *r*-process produces ~half of elements heavier than Fe

courtesy J. Lippuner



The decay of synthesized elements powers a "kilonova"

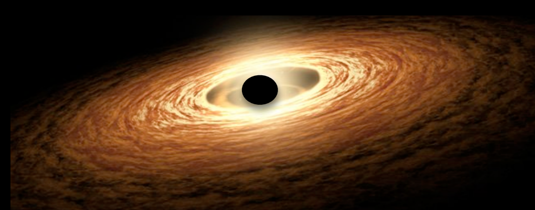
"kilonova"

- Mildly relativistic **neutron-rich** unbound material
- Synthesis of heavy elements

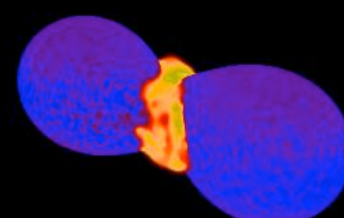
→ An expanding cloud heated by radioactive decays

tidally stripped

disk outflows

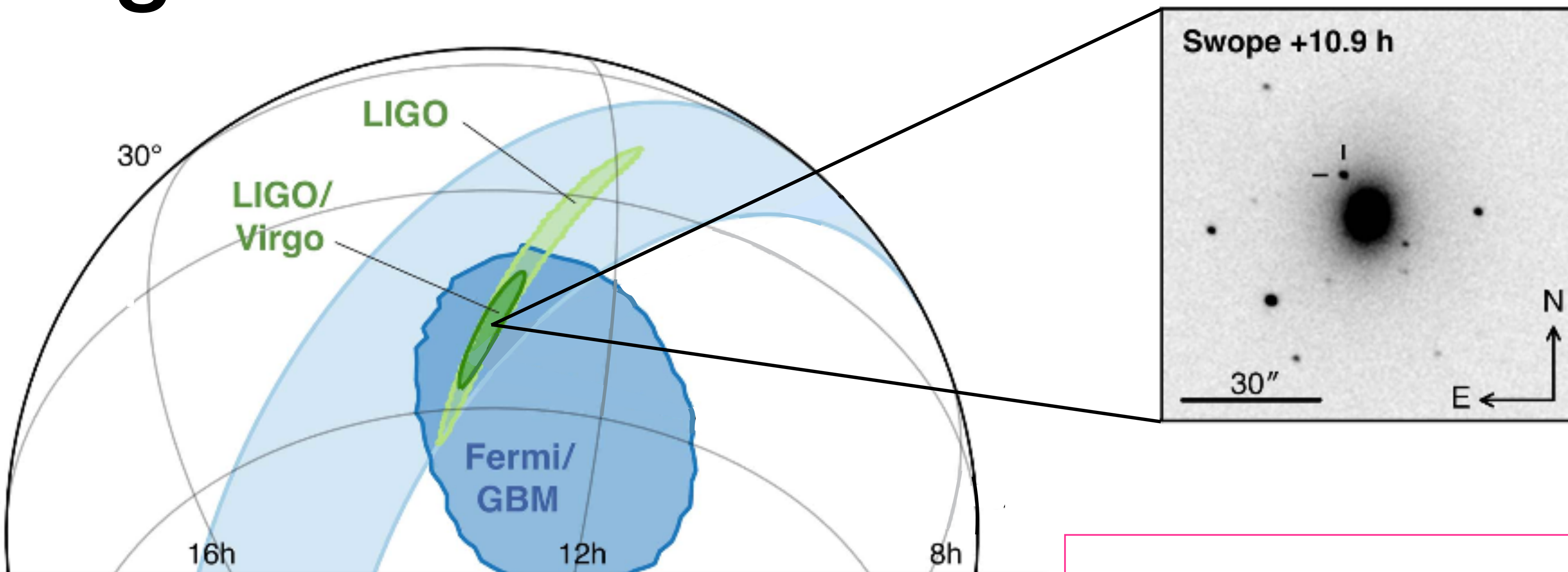


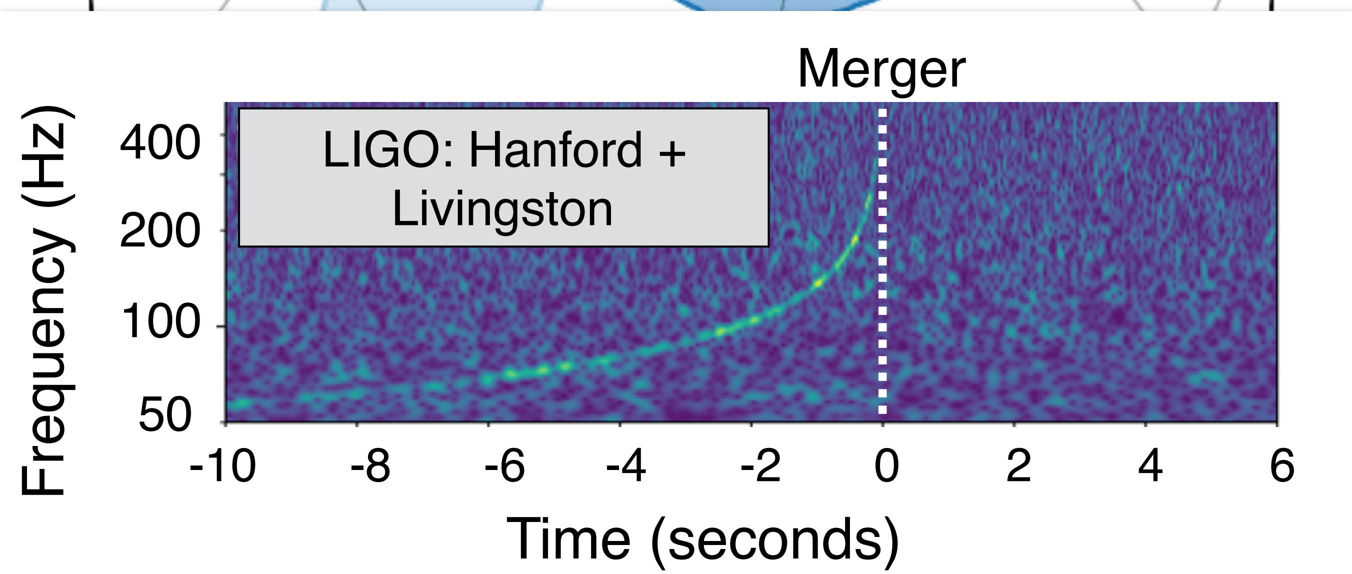
dynamically squeezed

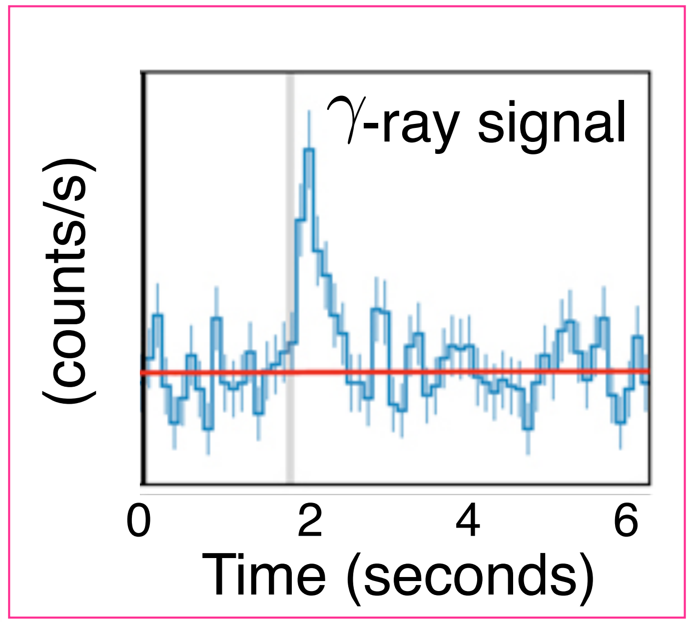


GW170817: the first neutron-star merger

ad. Abbot et al. 2017

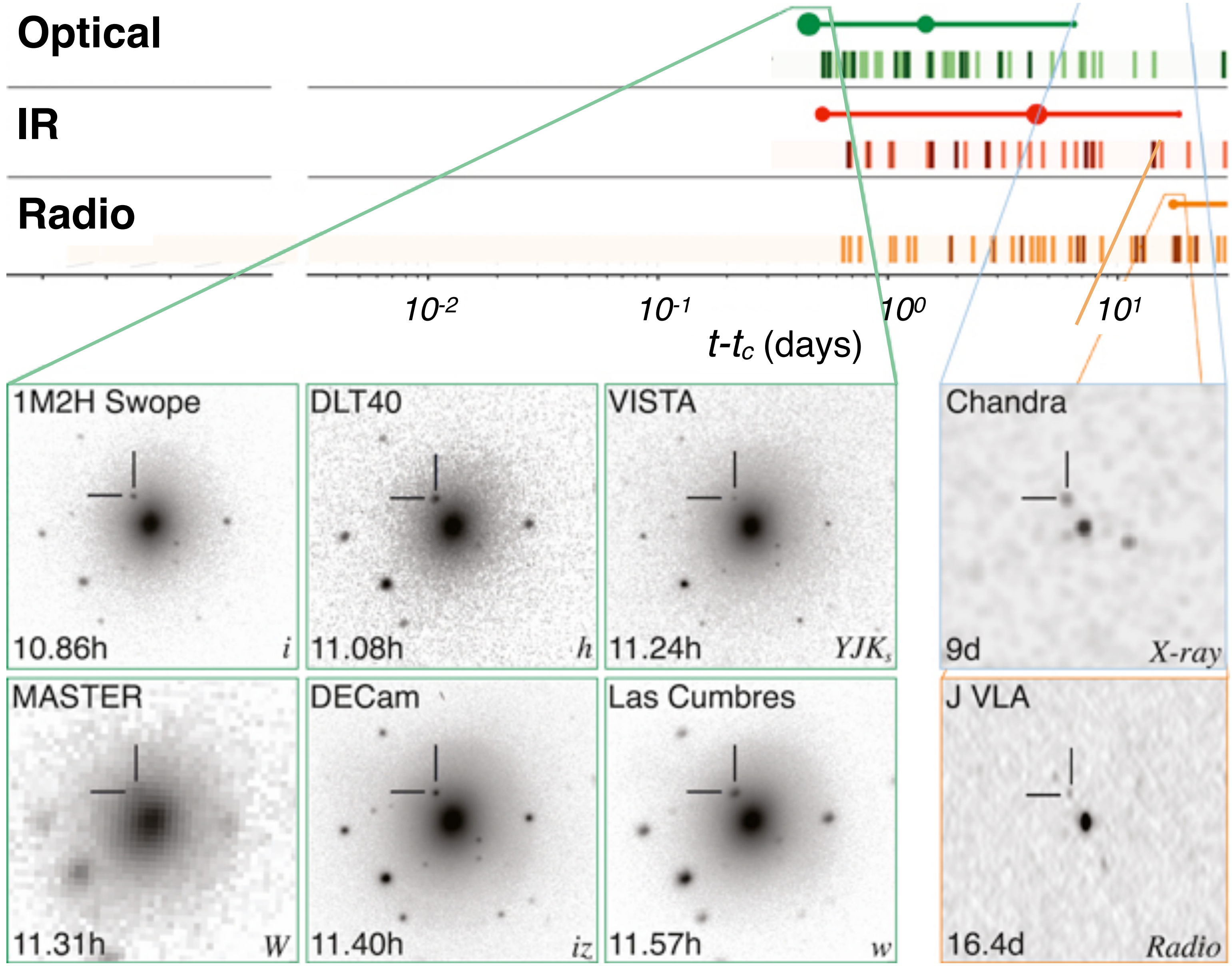






GW170817: the first neutron-star merger

transient source detected in galaxy NGC 4993



ad. from ALV + EM Partners 17

GW170817: the first neutron-star merger

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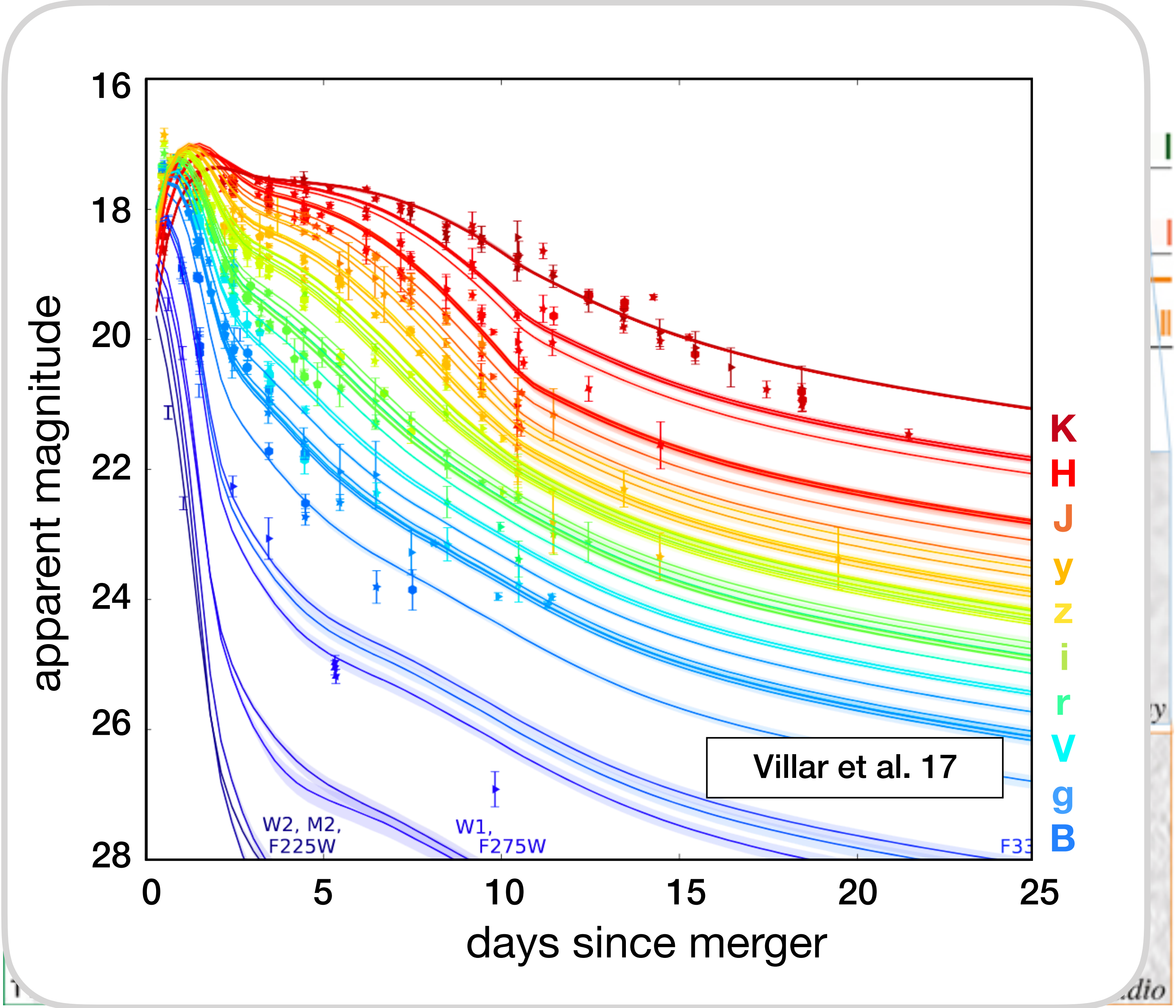

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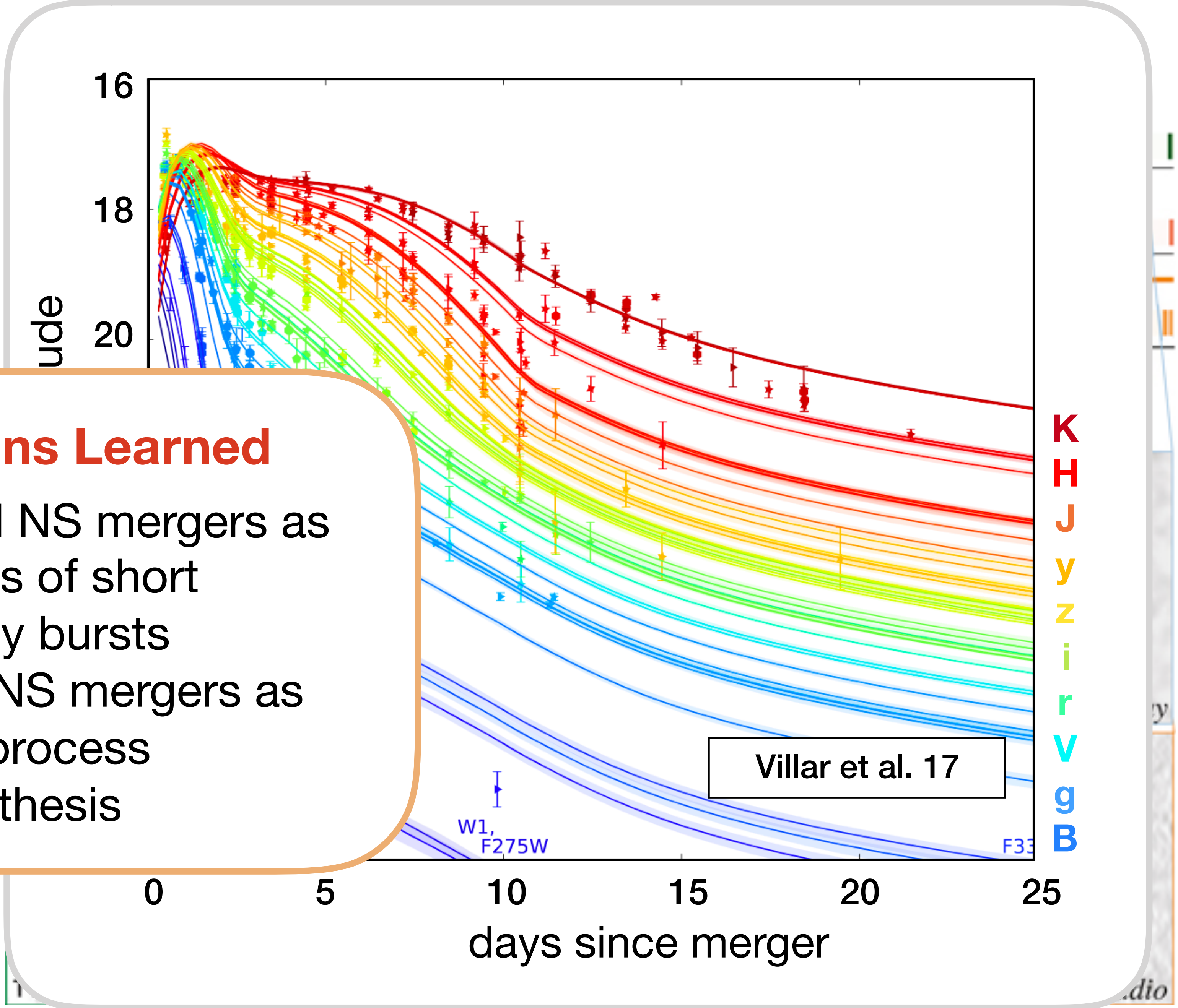
GW170817: the first neutron-star merger



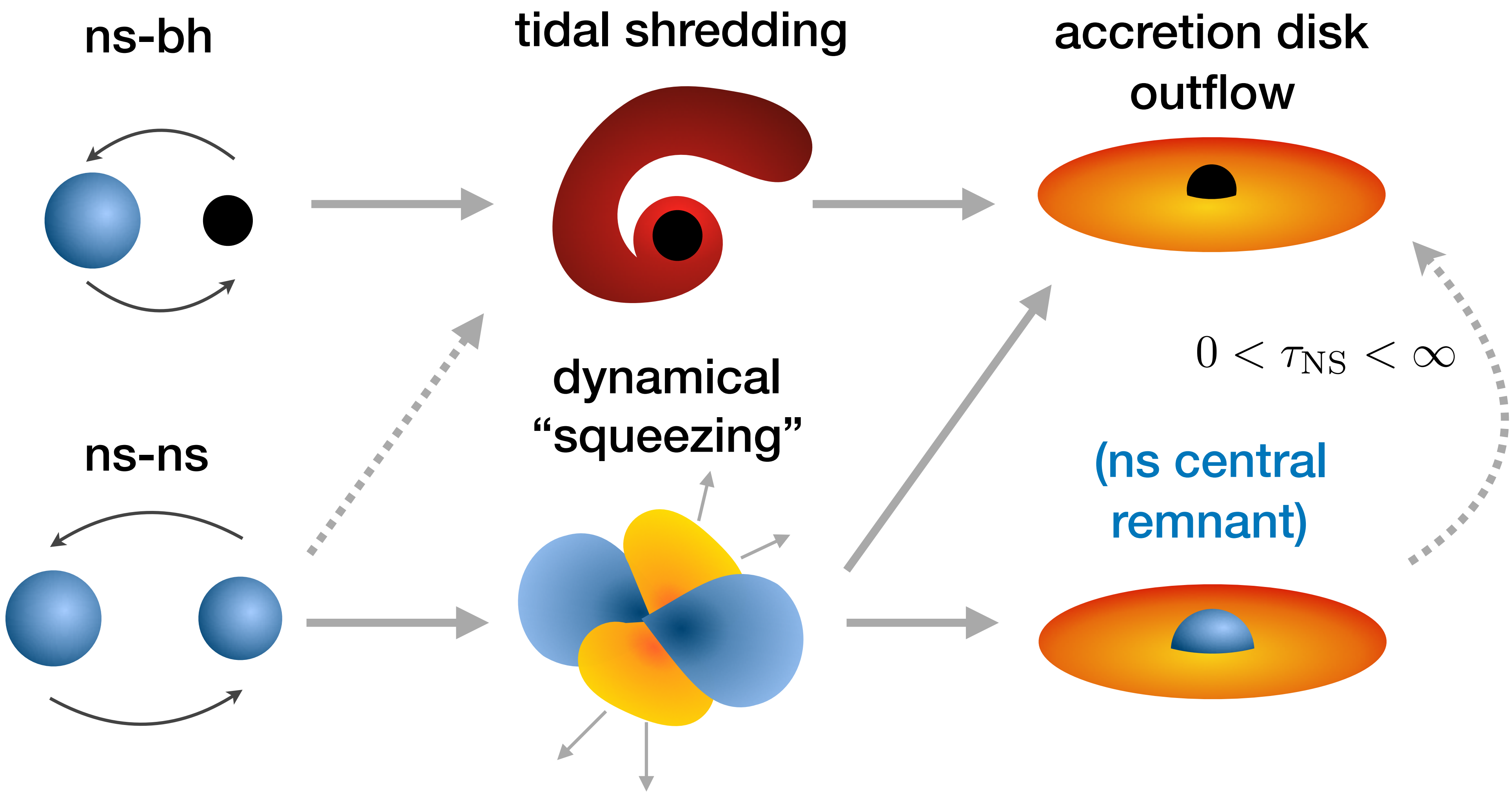
ad. from ALV + EM Partners 17

Lessons Learned

- Confirmed NS mergers as progenitors of short gamma-ray bursts
- Identified NS mergers as sites of *r*-process nucleosynthesis

A clearer picture of the ejecta is crucial for progress

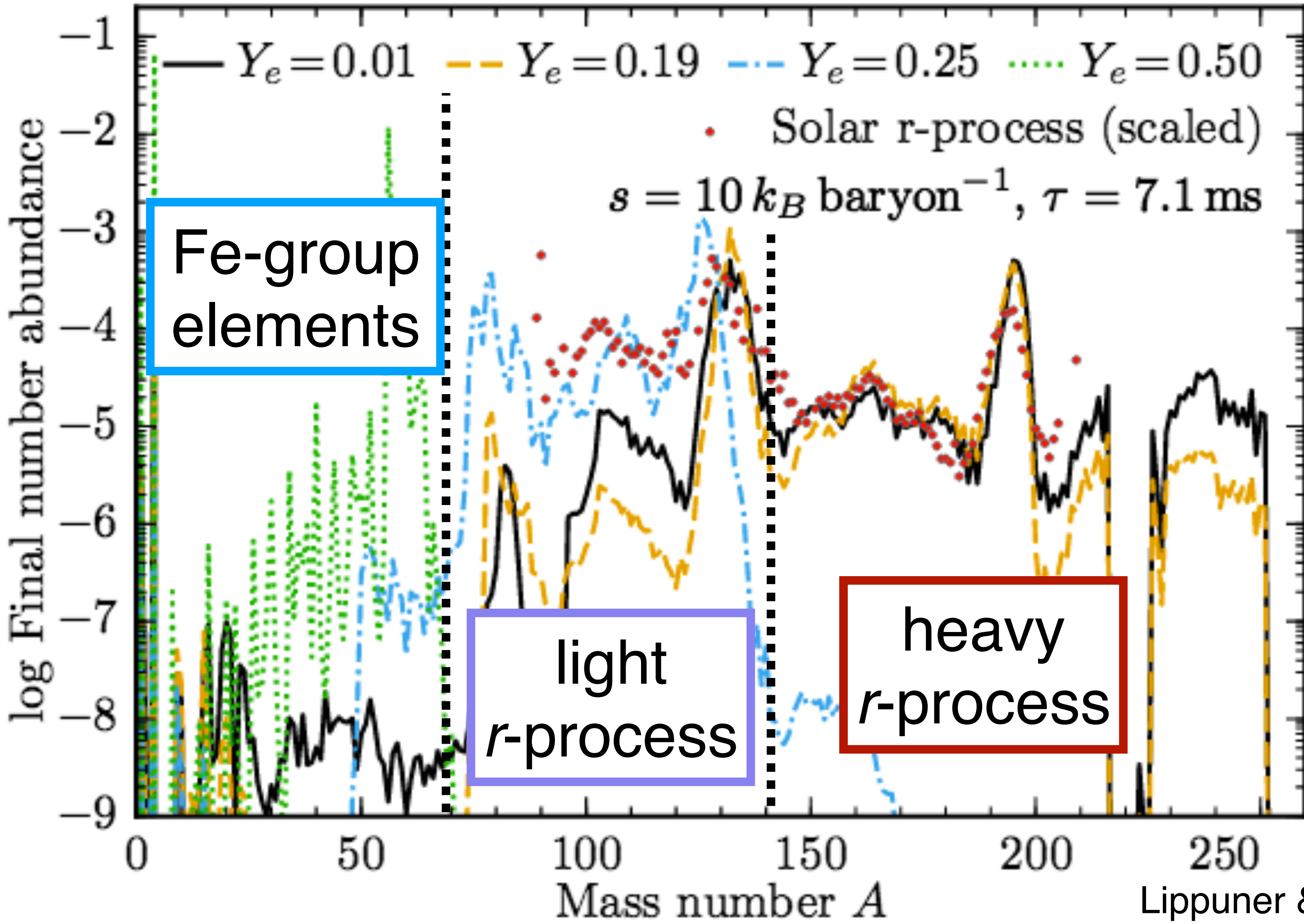
How much mass was ejected, at what velocity, and with what composition?



Interpreting the GW170817 kilonova

Outcomes of the *r*-process

fewer free n per seed ⟷ more free n per seed



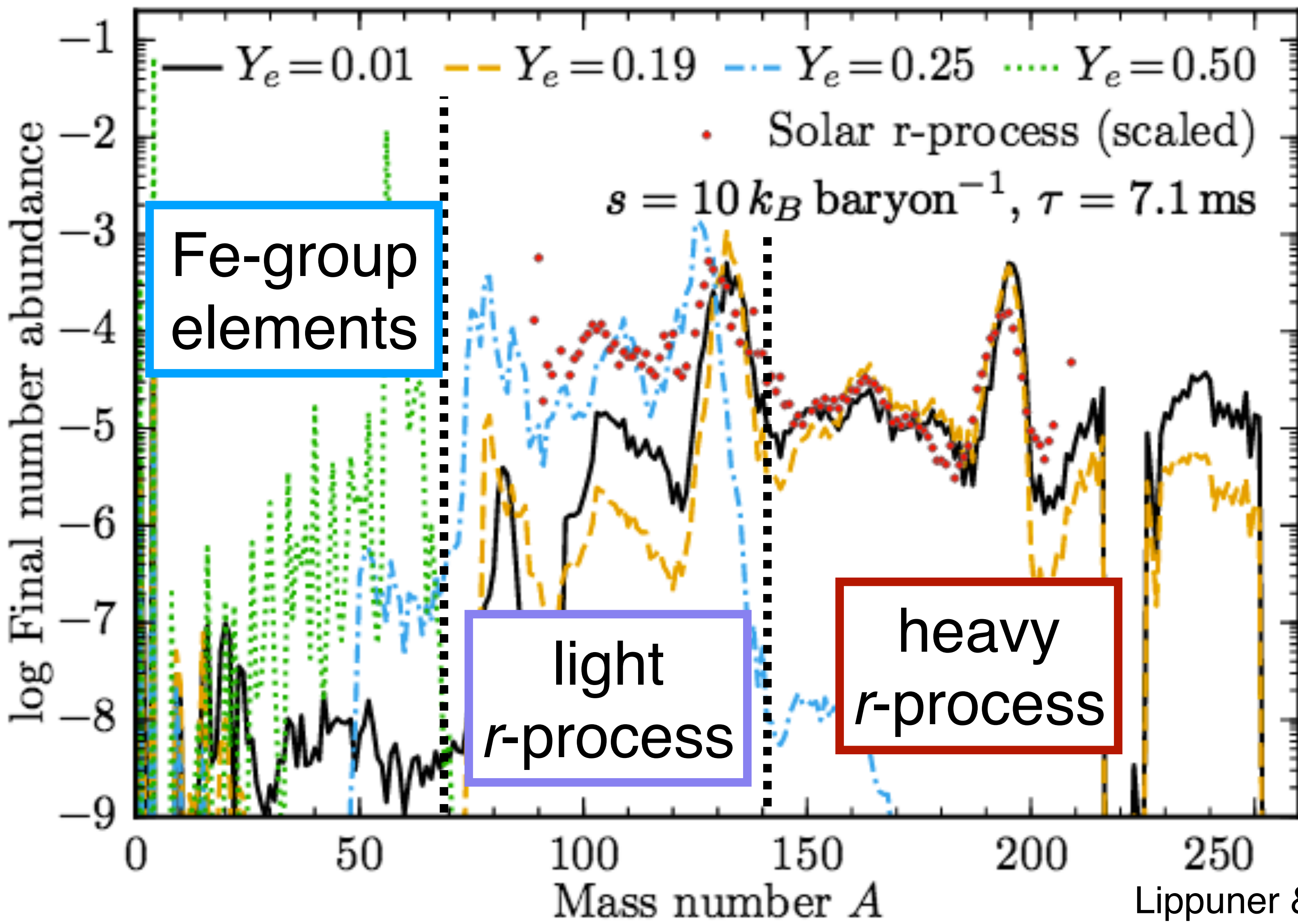
$$Y_\mathrm{e} = \frac{p}{p+n}$$

Lippuner & Roberts 2015

Interpreting the GW170817 kilonova

Outcomes of the *r*-process

fewer weak interactions ⟷ more weak interactions



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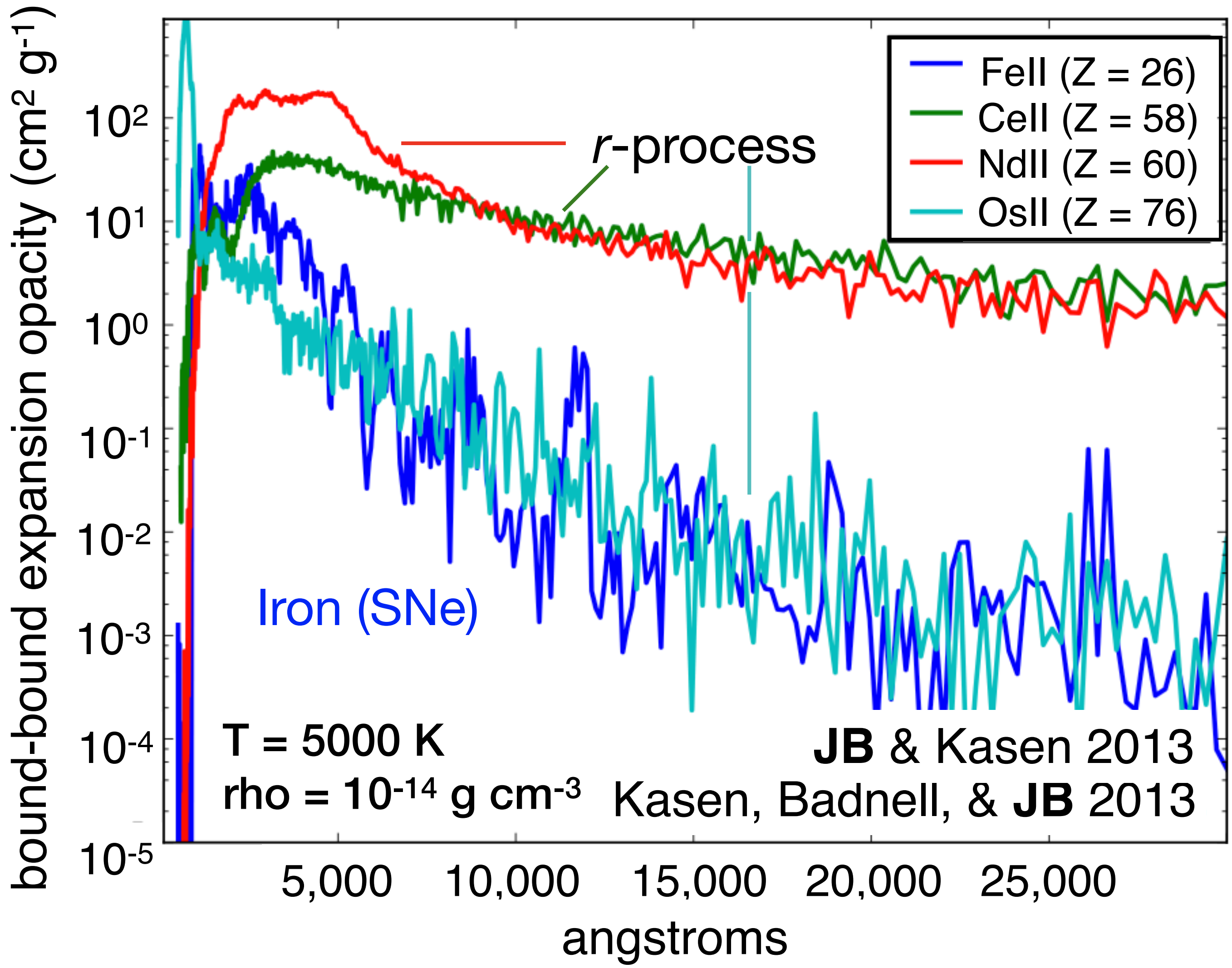
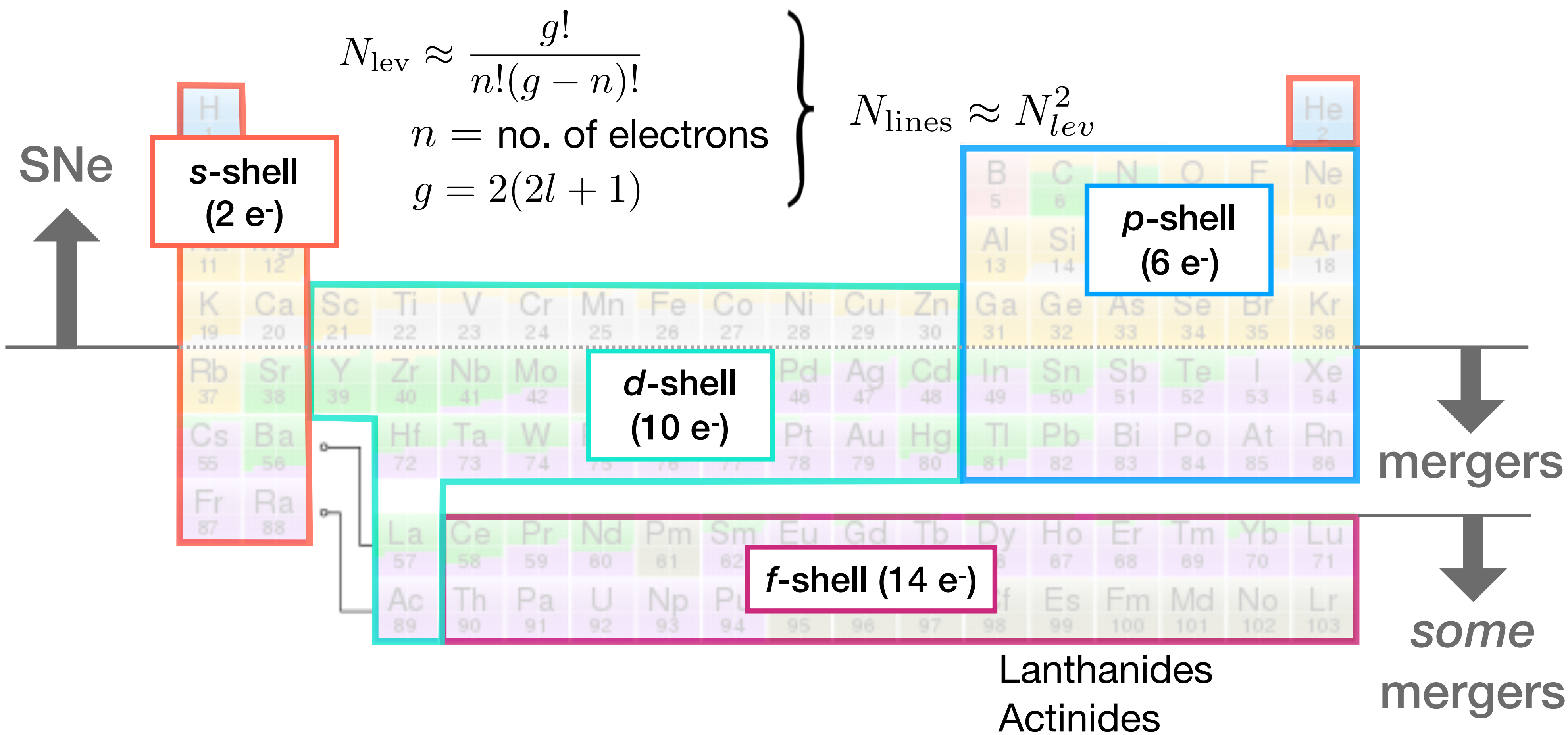
Kilonova opacities depend on composition/nucleosynthesis



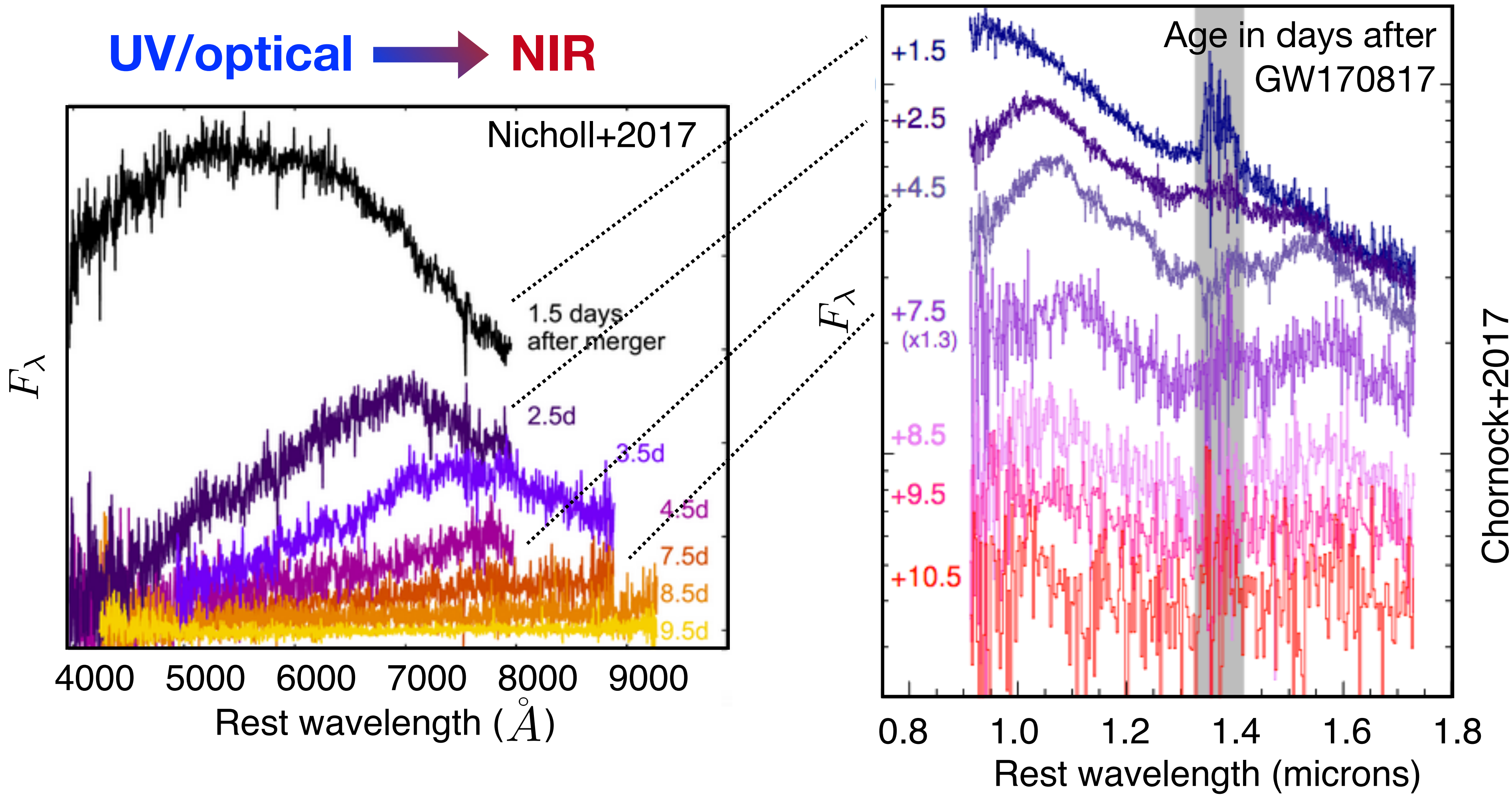
Kilonova opacities depend on composition/nucleosynthesis

Opacity is correlated with atomic structure



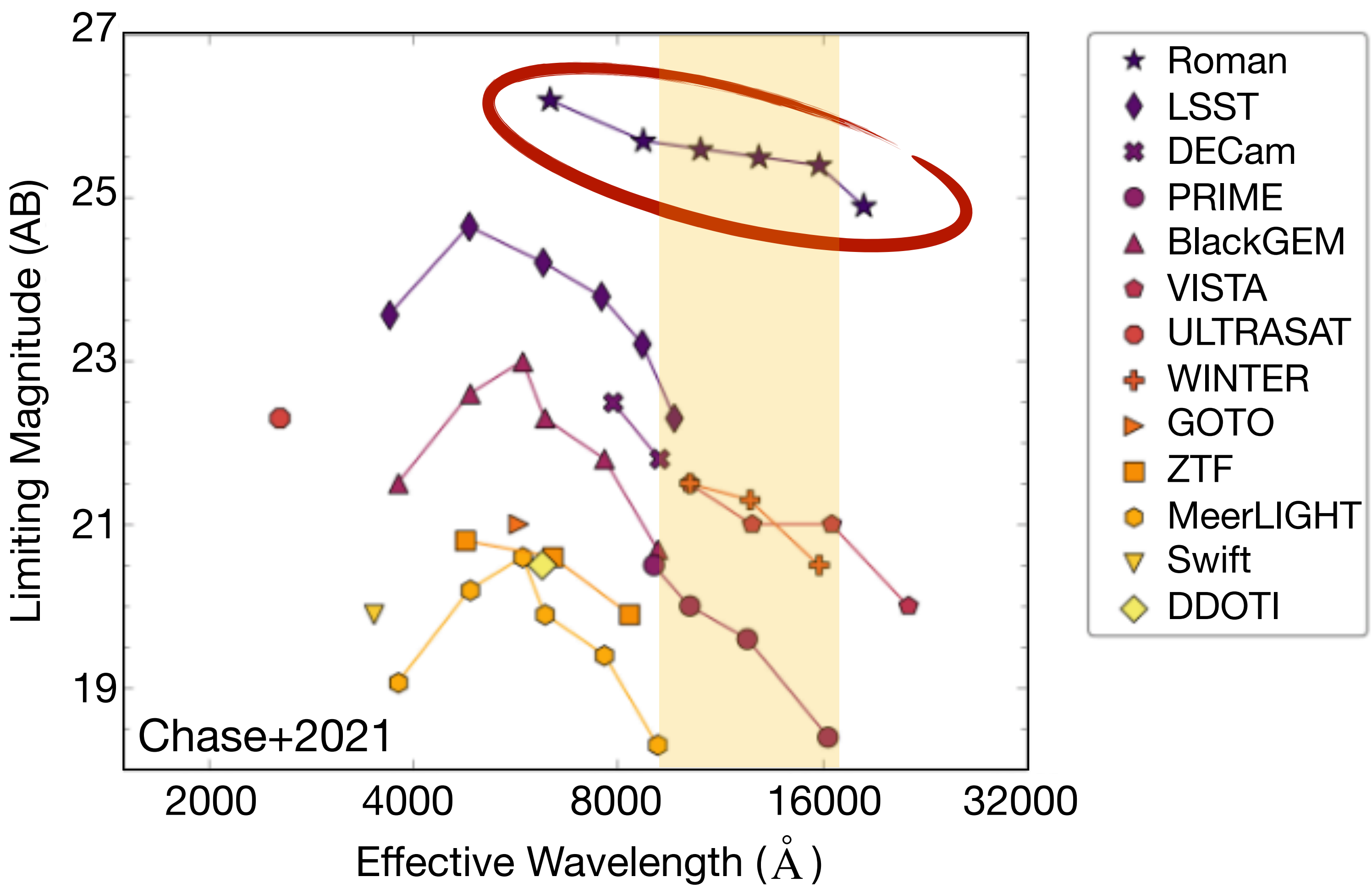
Kilonova opacities depends on composition/nucleosynthesis

GW170817 showed evidence of multiple outflows with distinct patterns of nucleosynthesis



Roman is a powerful tool for kilonova discovery

It is uniquely sensitivity in near infrared bands, allowing detections of kilonovae out to high redshifts



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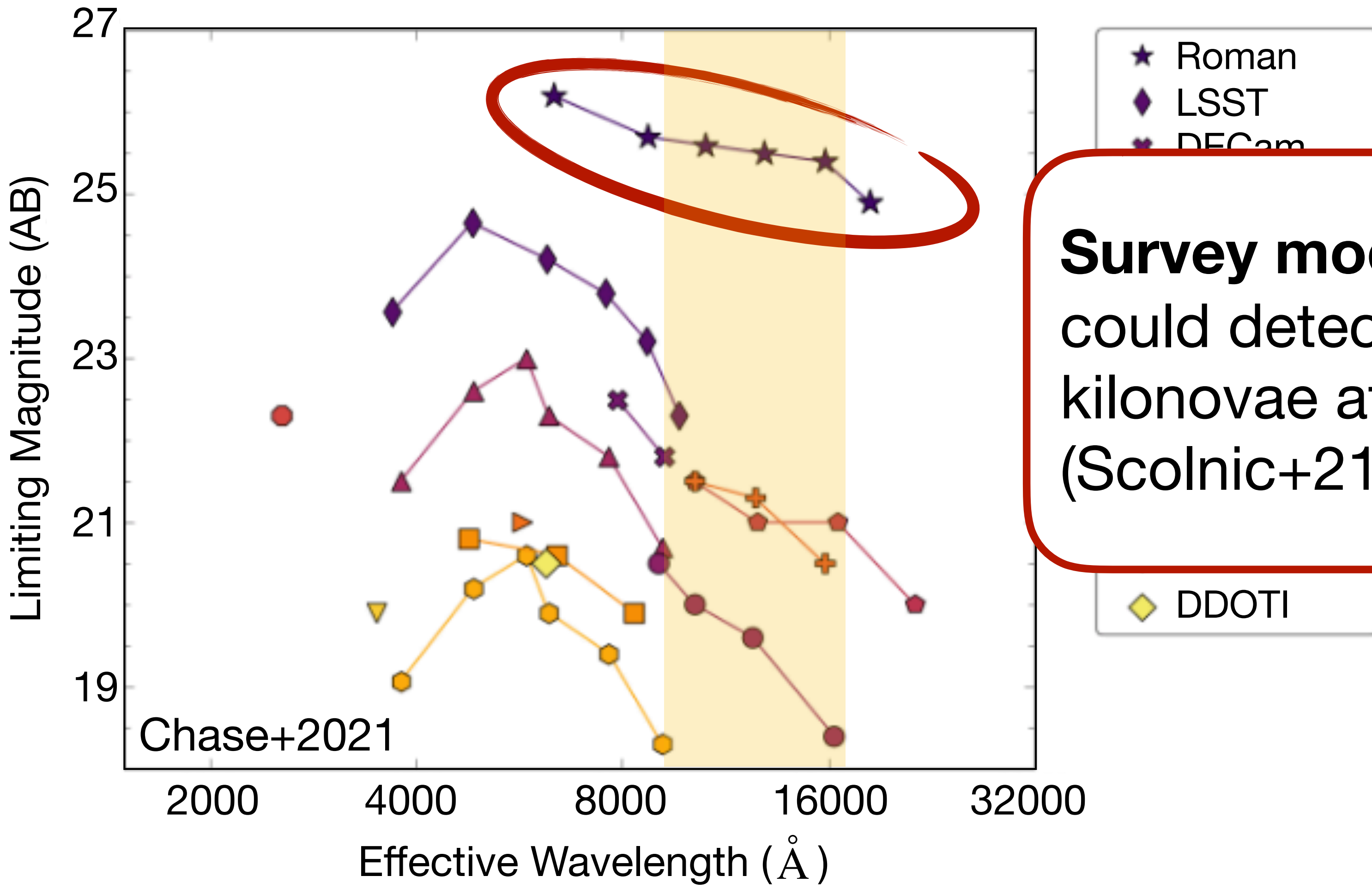
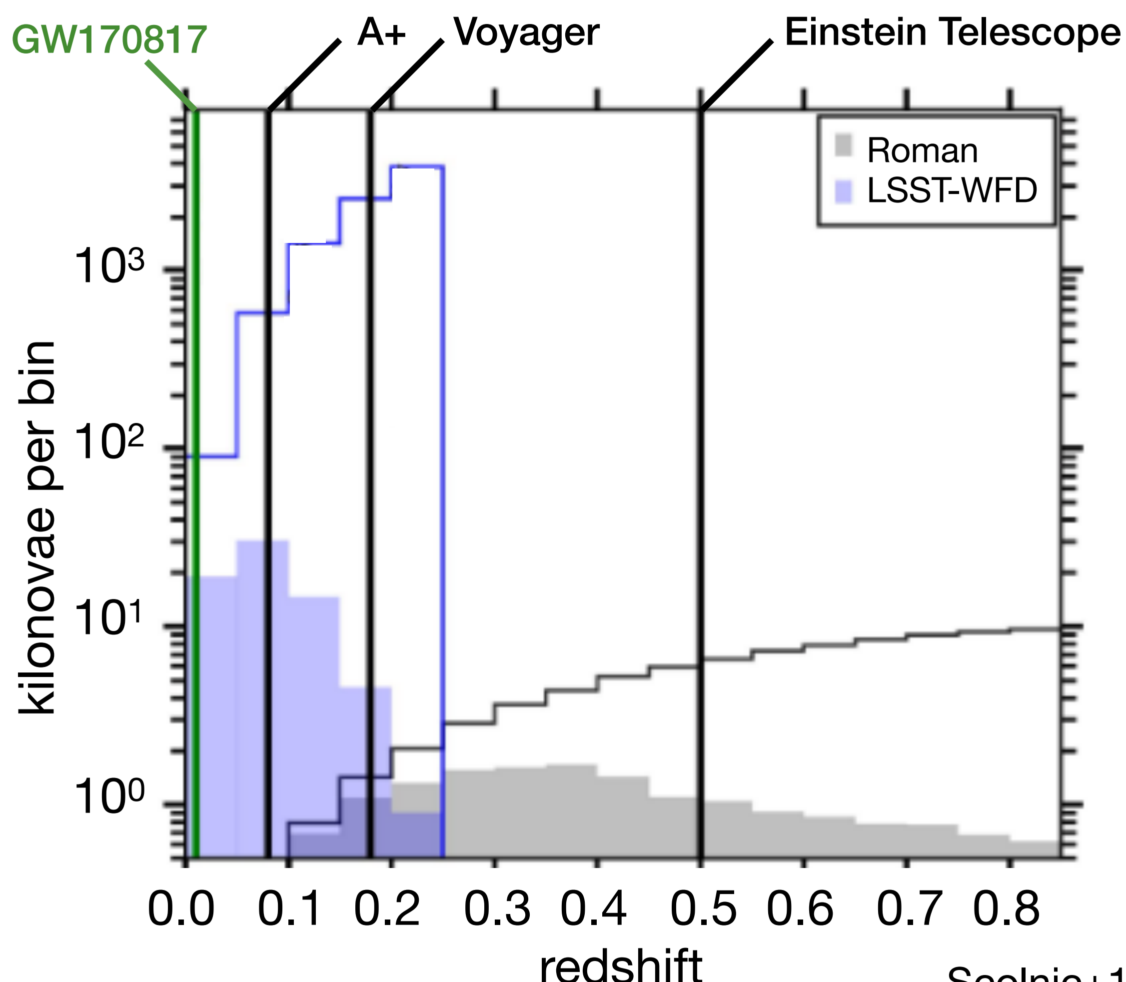


Survey mode: Roman could detect $\approx$16 kilonovae at $z \sim 0.1 - 0.8$ (Scolnic+21)

Roman is [could be] a powerful tool for gravitational-wave follow-up

- Wide field of view (0.28 deg^2, 100x Hubble's) can efficiently search large GW sky localizations
- Sensitivity out to red wavelengths is increasingly important as advances on the GW side push the NS merger horizon to higher and higher redshifts



Scolnic+18

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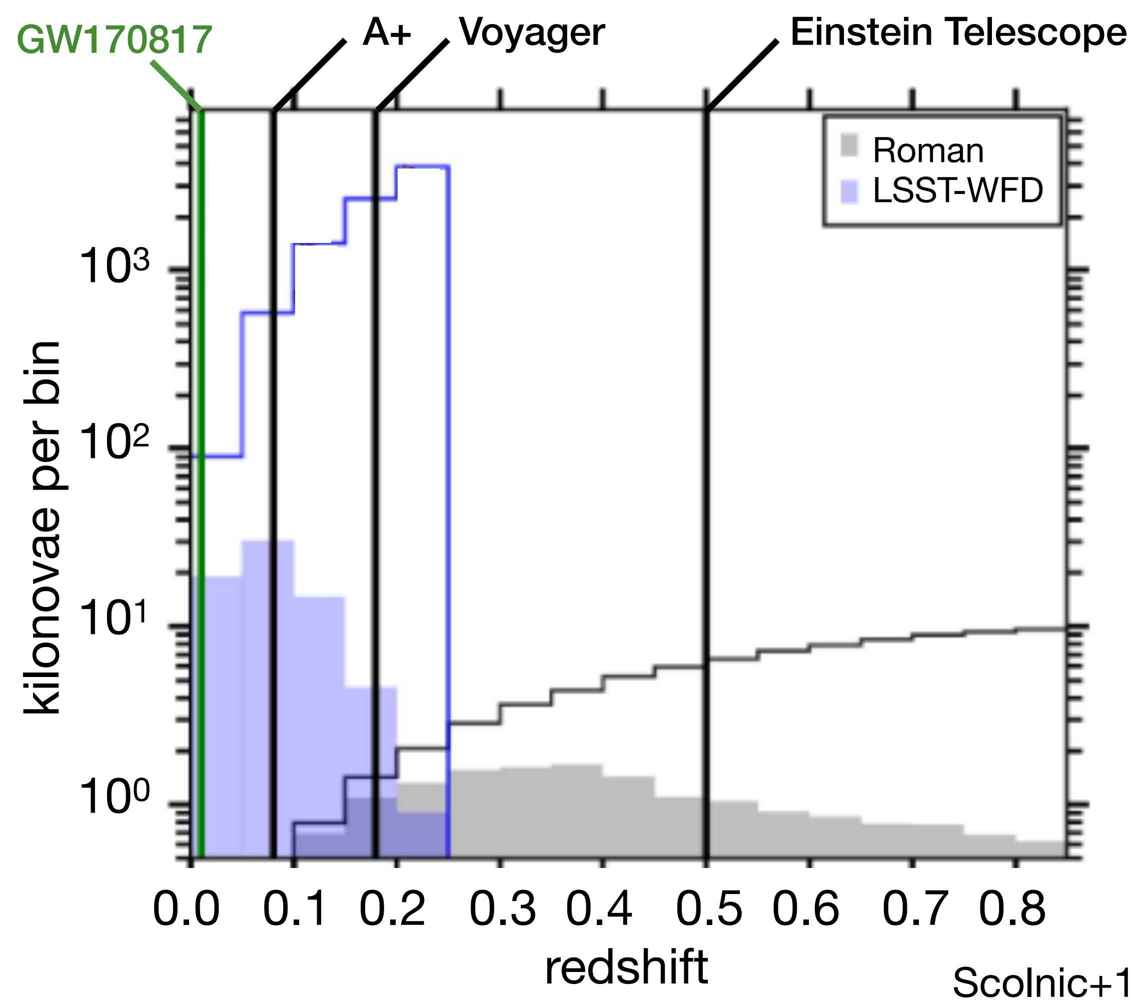
- Wide field of view (0.28 deg^2, 100x Hubble's) can efficiently search large GW sky localizations
- Sensitivity out to red wavelengths is increasingly important as advances on the GW side push the NS merger horizon to higher and higher redshifts
- Follow-up is not limited to photometry!



Scolnic+18