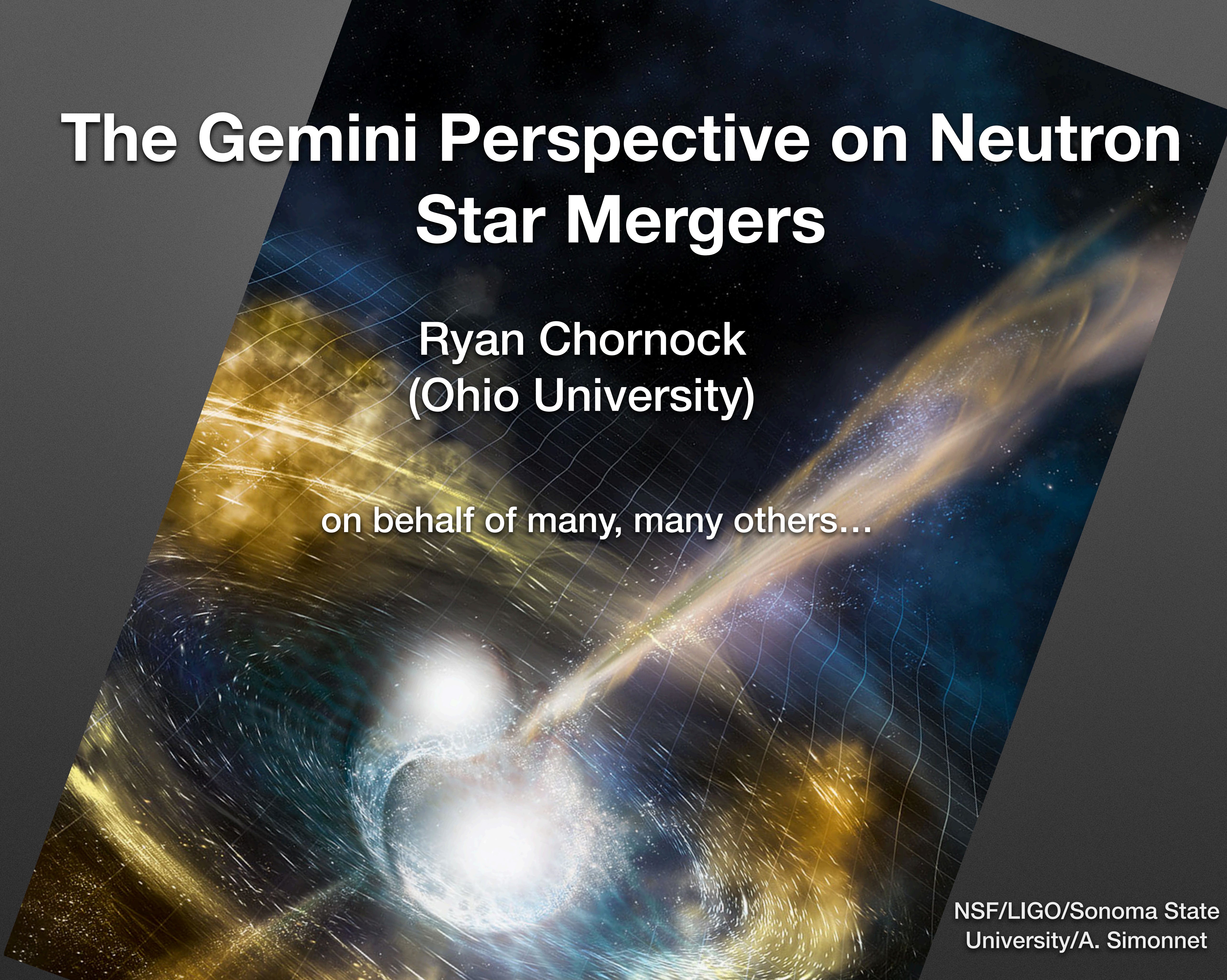
The Gemini Perspective on Neutron Star Mergers

Ryan Chornock
(Ohio University)

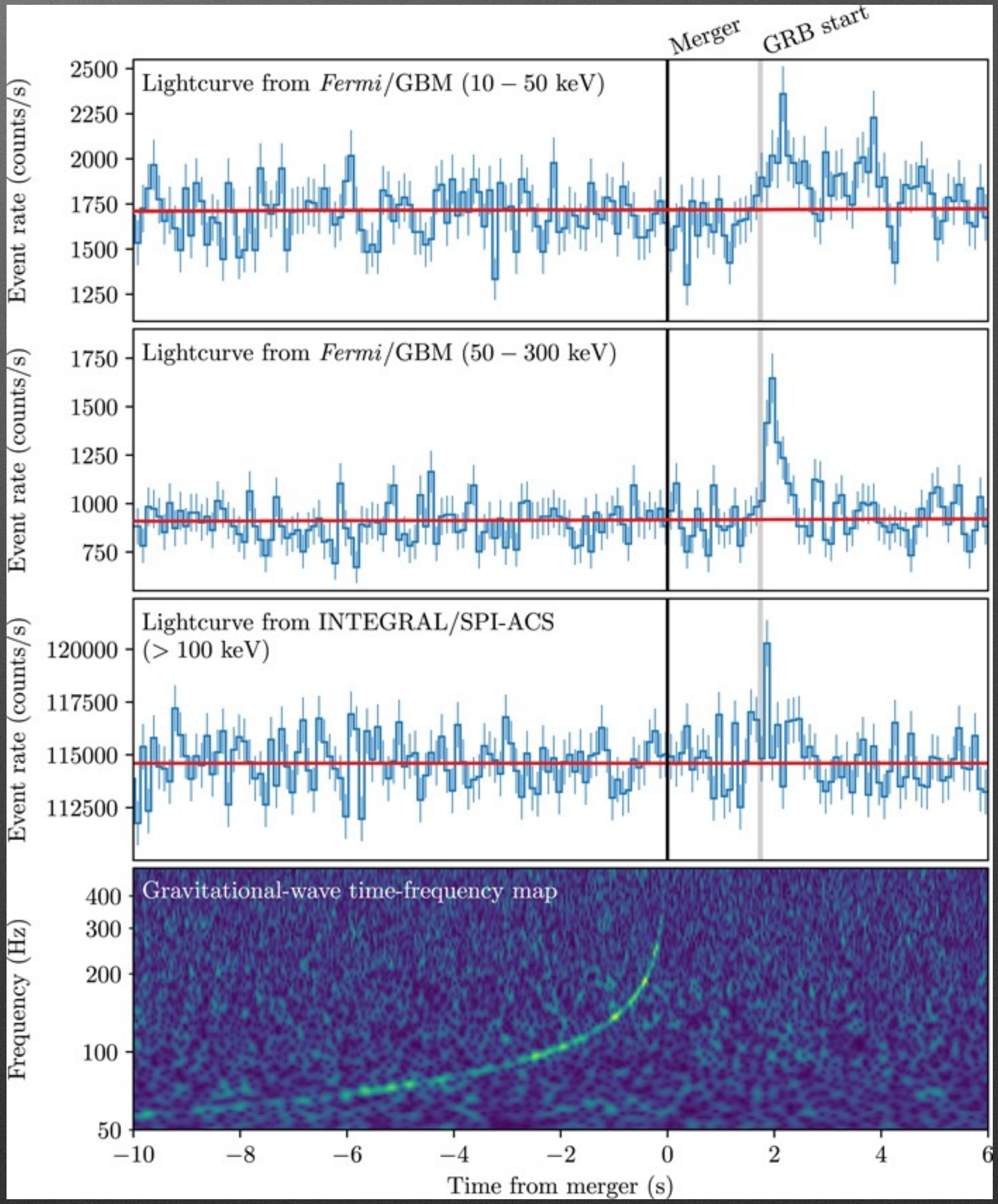
on behalf of many, many others…



NSF/LIGO/Sonoma State University/A. Simonnet

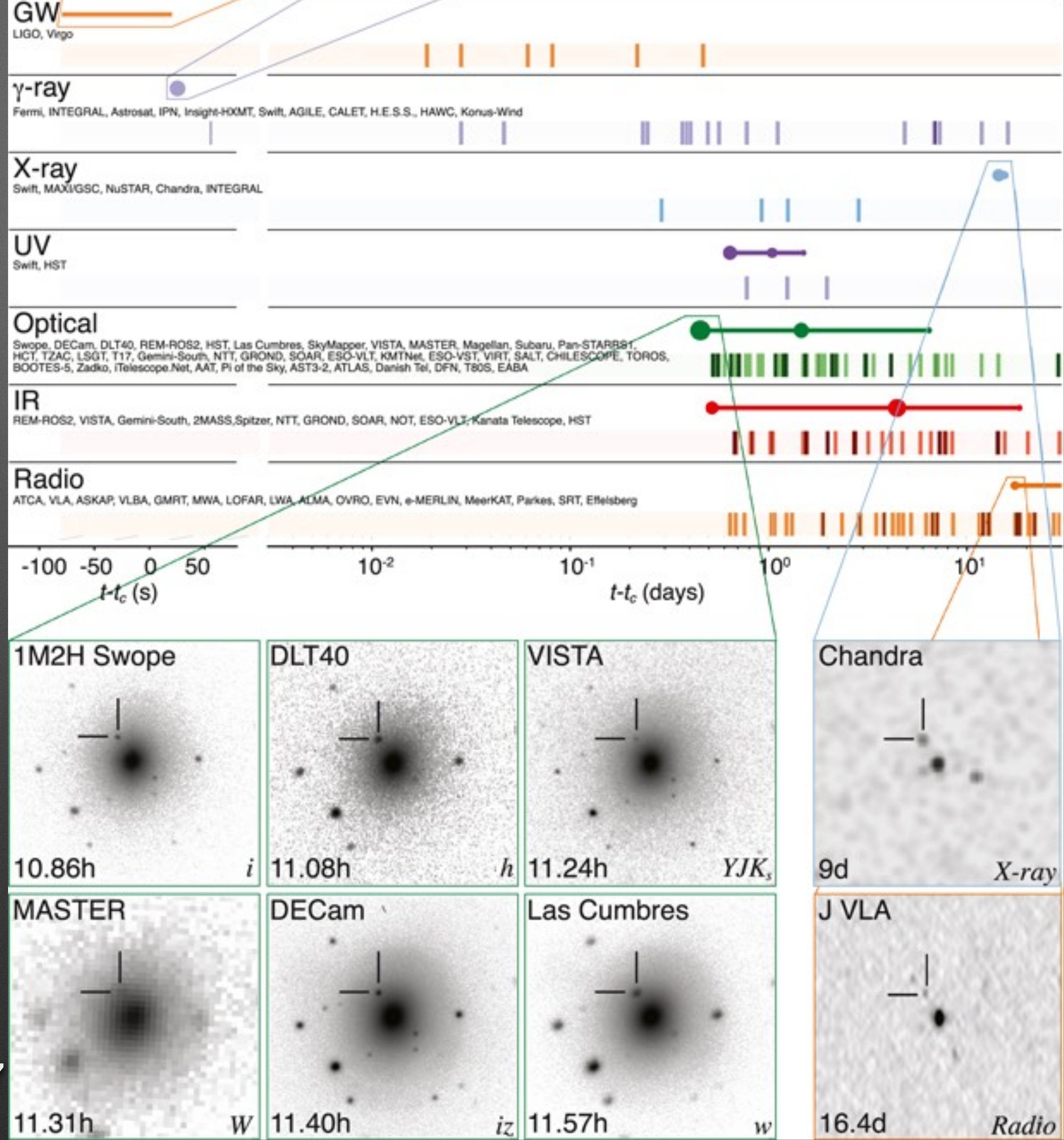
GW170817

- On August 17, 2017, Advanced LIGO/Virgo triggered on a low-mass merger consistent with being a binary neutron star merger
- Followed 1.7 s later by a spatially coincident weak burst of gamma rays



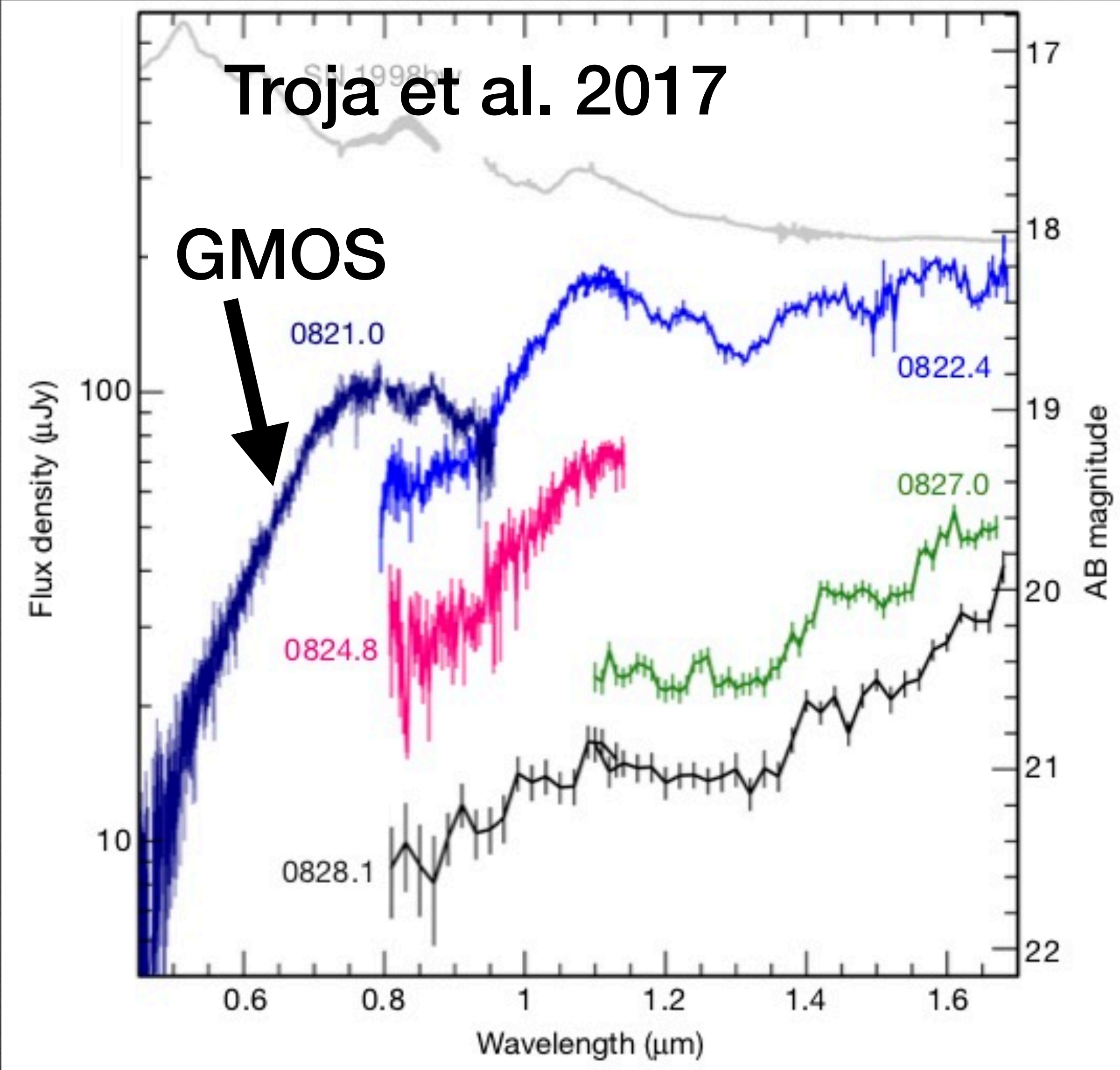
LVC/Fermi/Integral

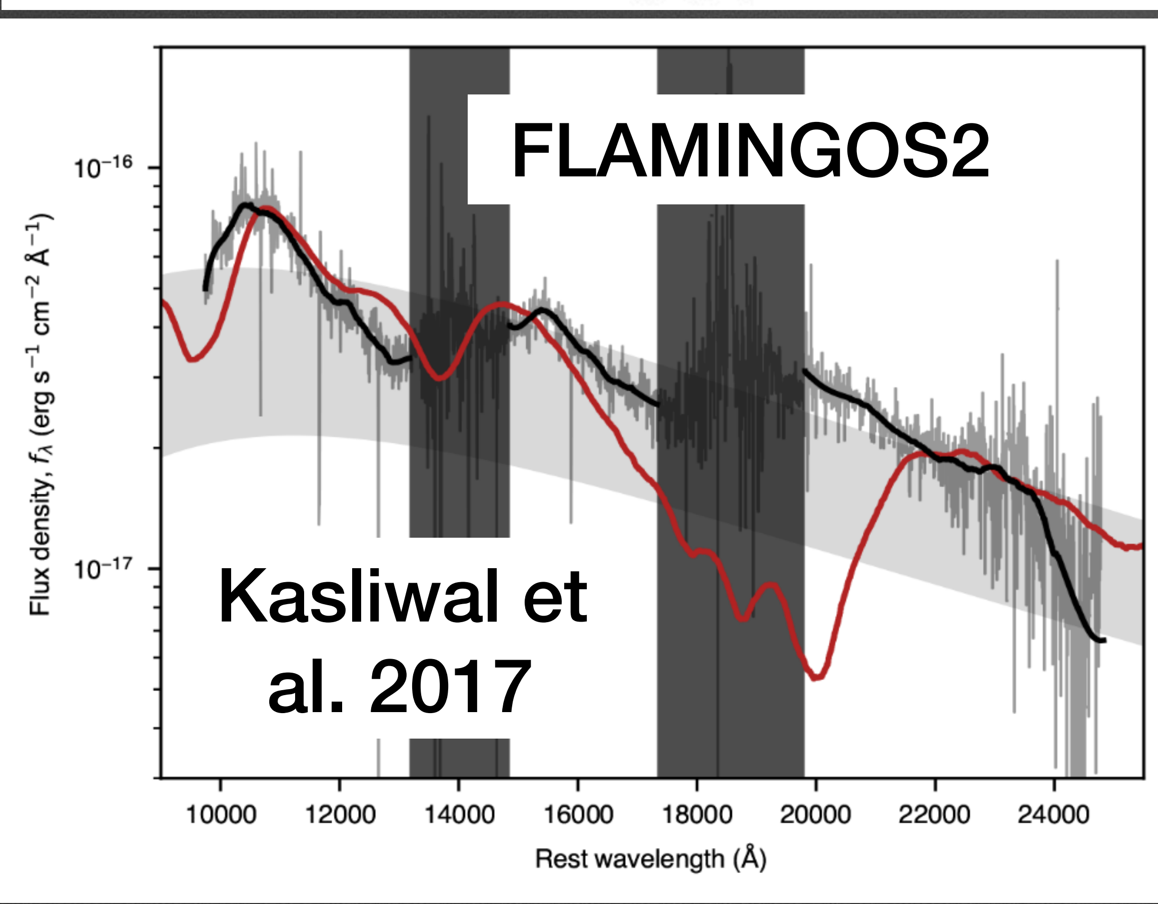
- The optical counterpart, SSS17a, was independently found by 6 optical followup teams, first by the 1M2H collaboration using the Swope
- More than 70 telescopes participated in the followup effort

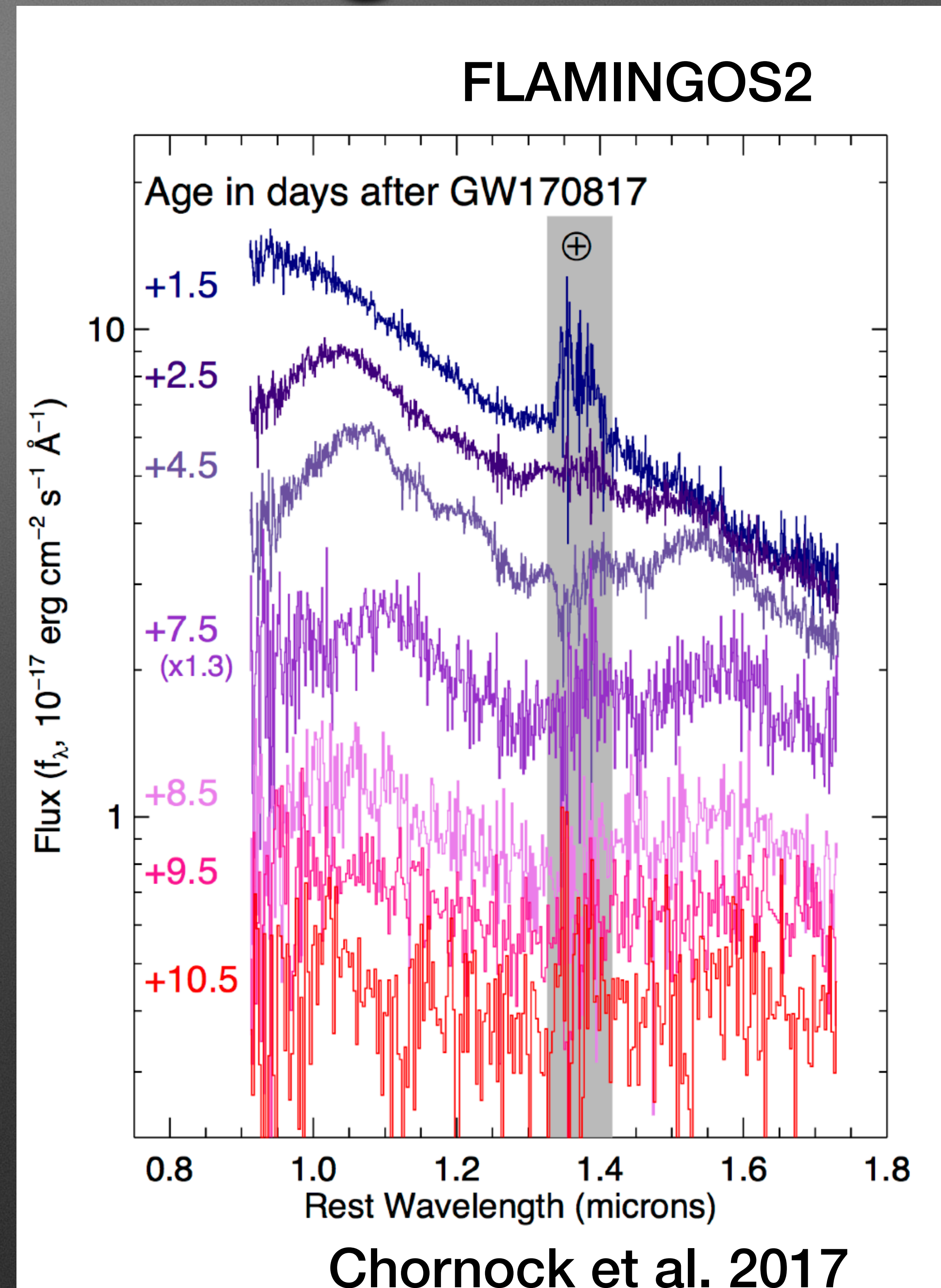


LVC/EM partners 2017

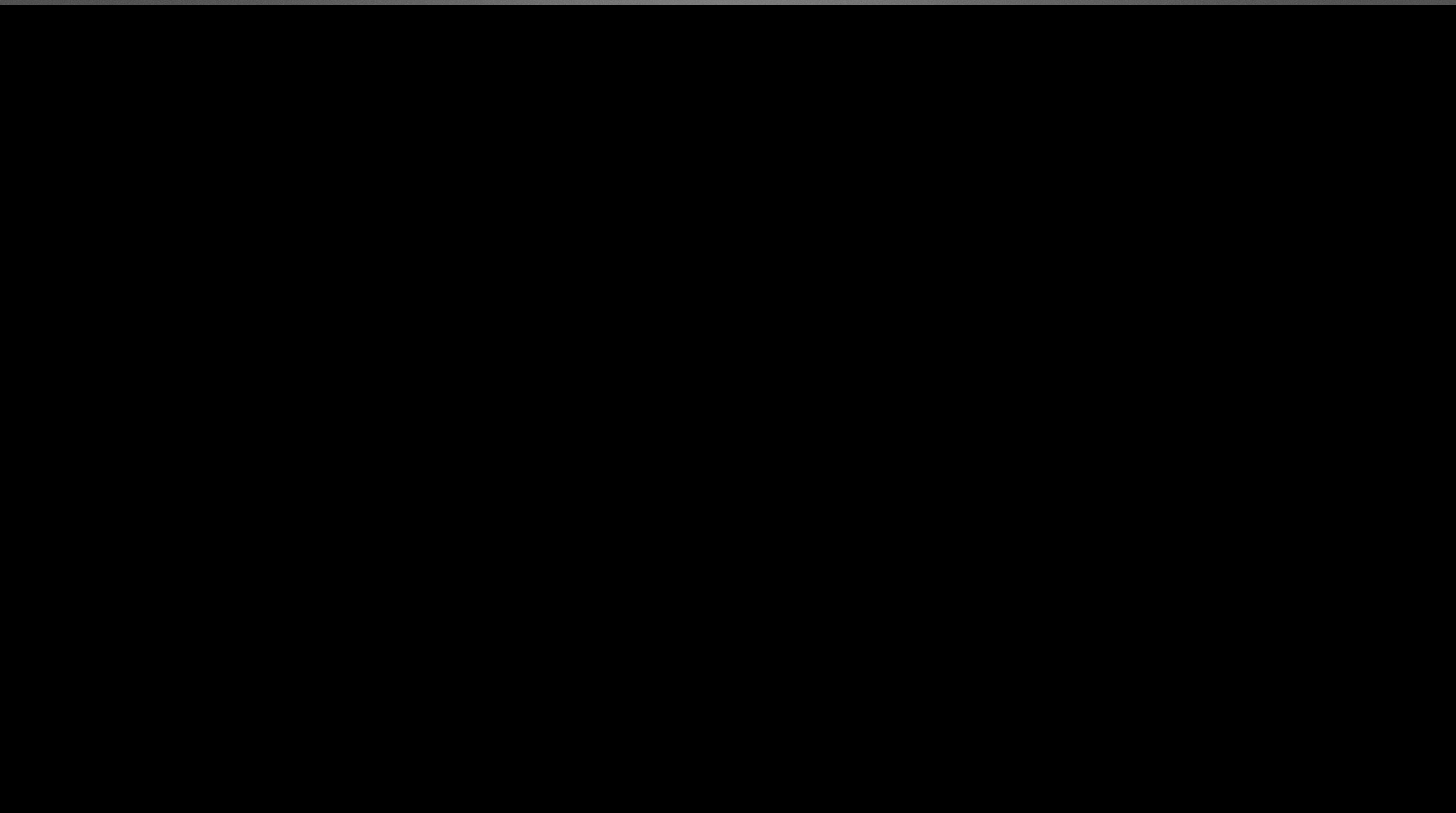
Including Gemini!





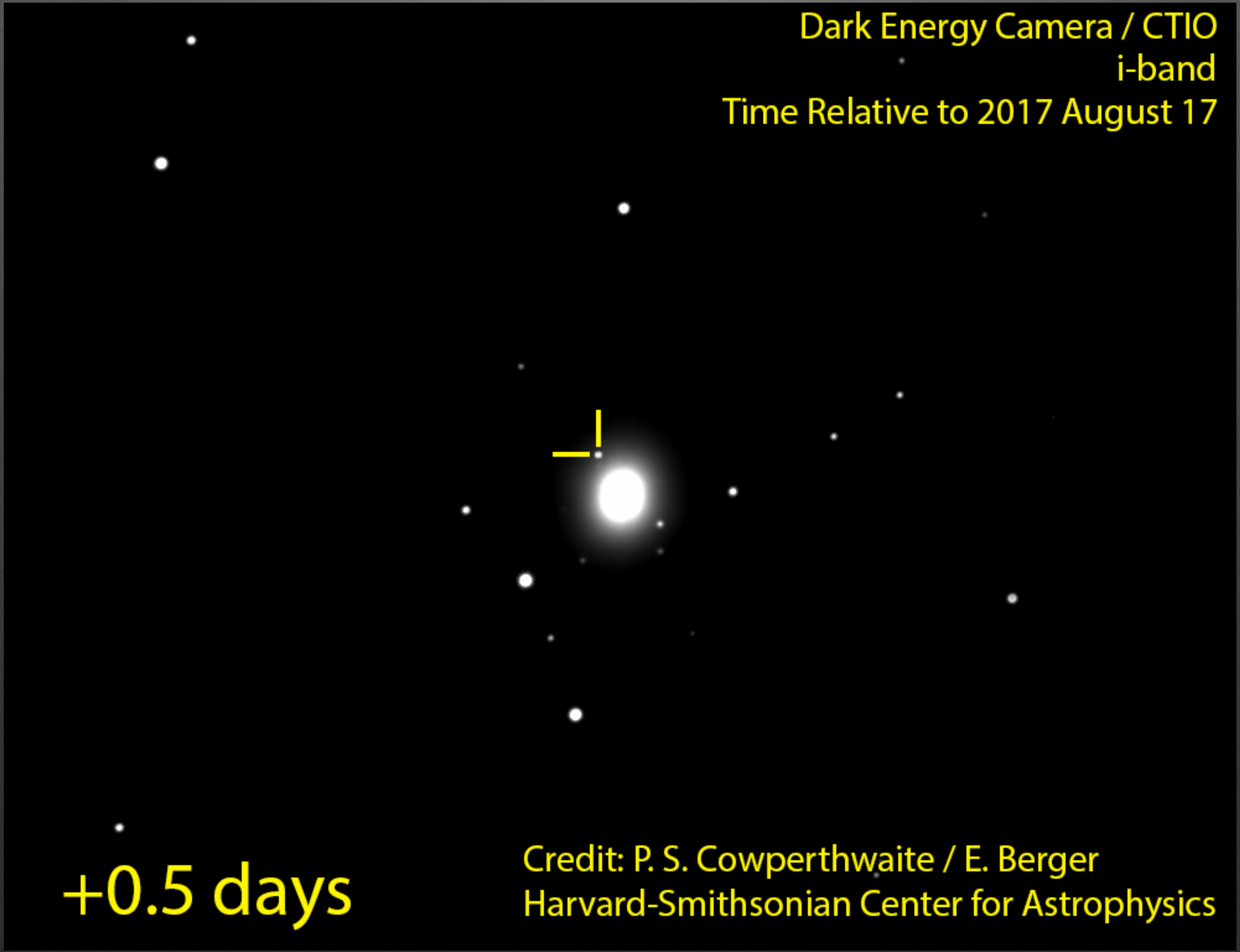


What happens in a BNS merger?

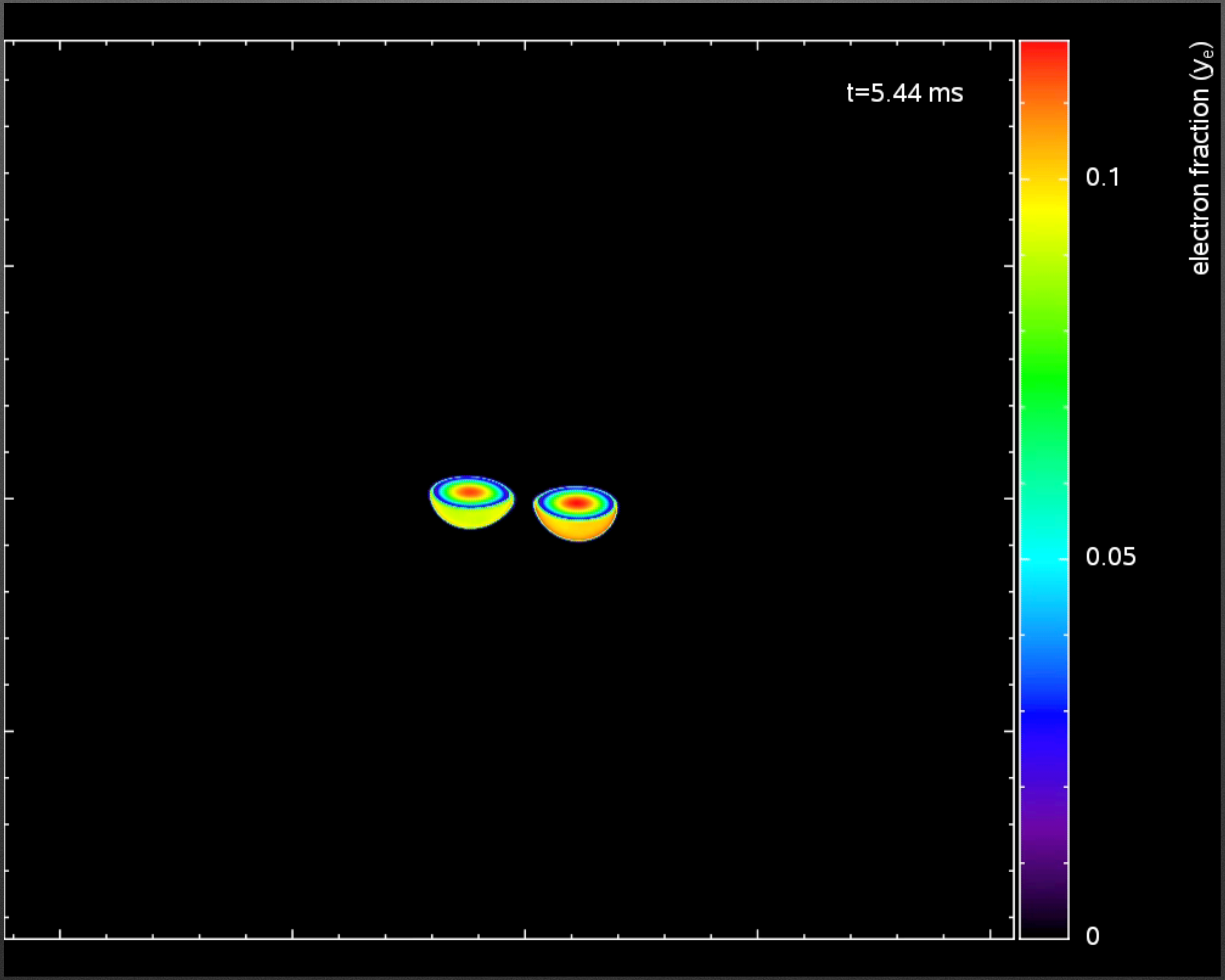


NASA's Goddard Space Flight Center/CI Lab

What we actually see



Neutron Star Mergers

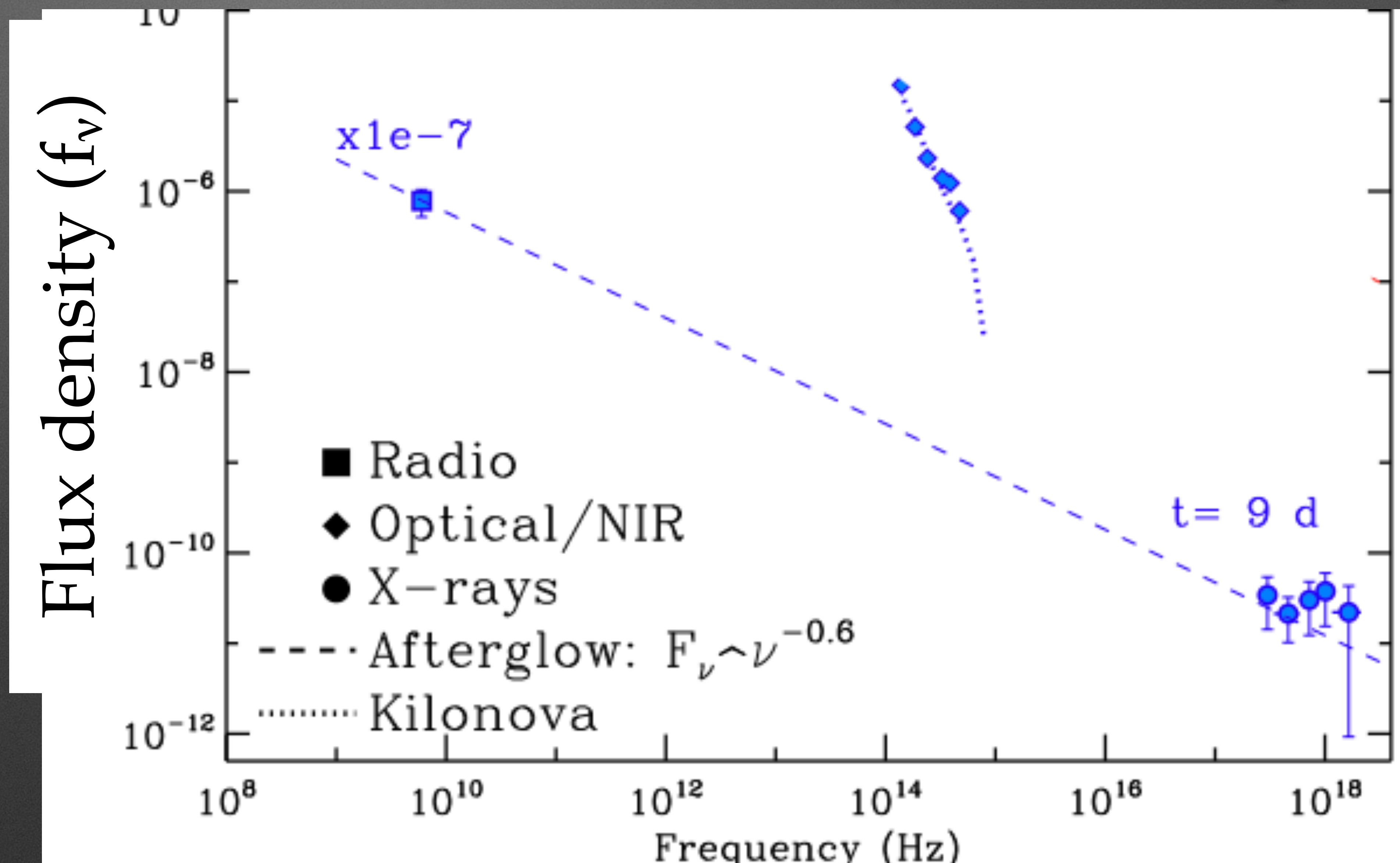


S. Rosswog

Two Emission Processes

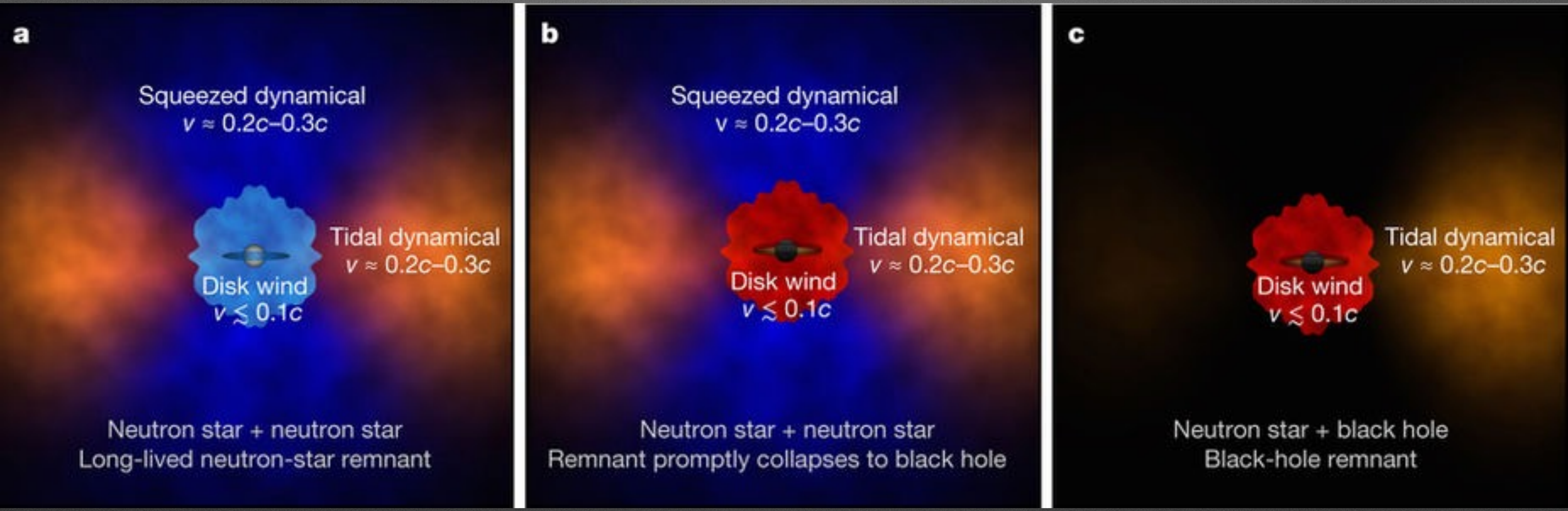
- Optical through IR dominated by “thermal” kilonova component
- Underlying X-ray to radio power law from synchrotron emission (jet)

Radio IR/Optical X-ray



Margutti et al. 2018

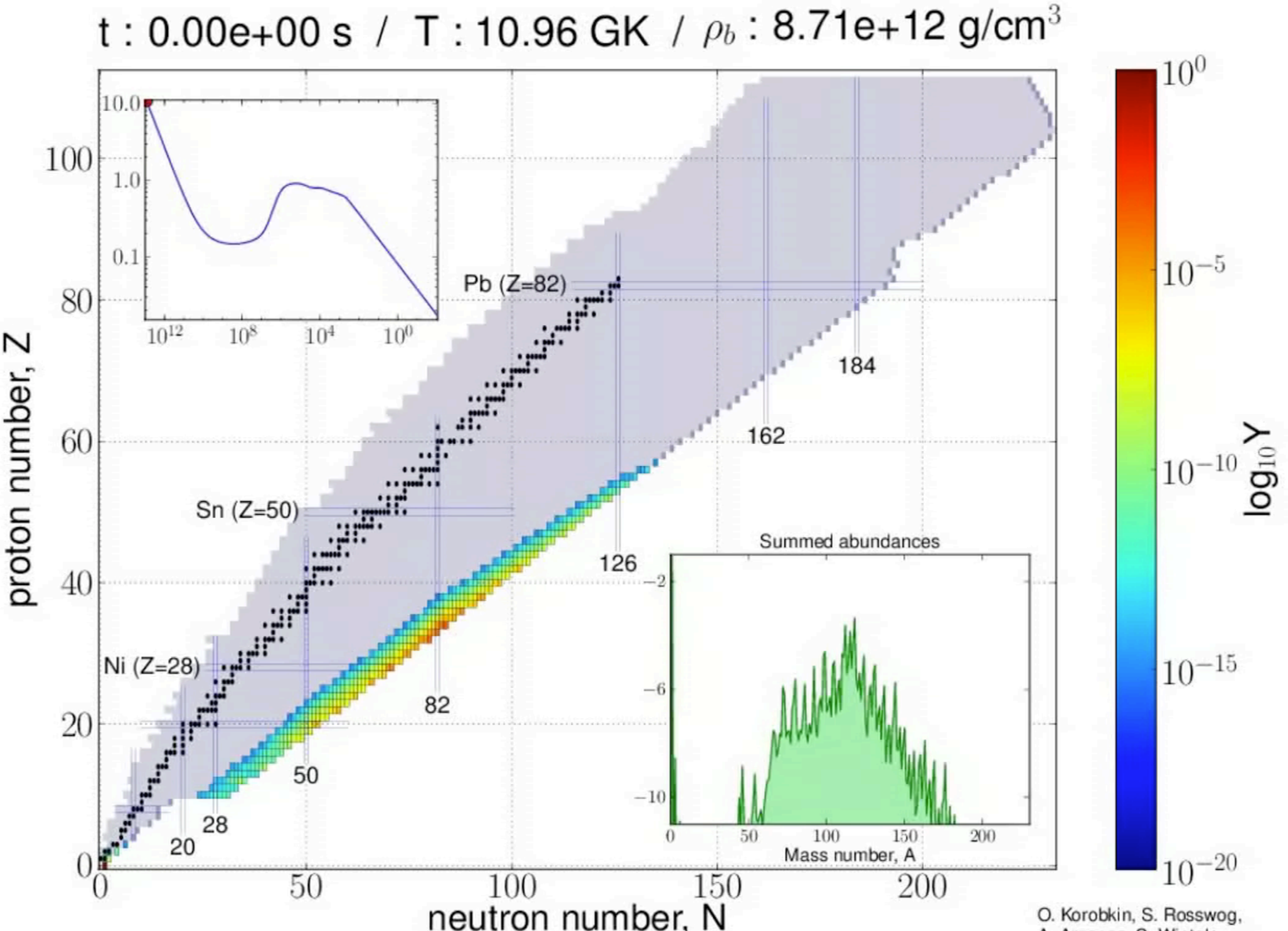
Kilonova components



Kasen et al. 2017

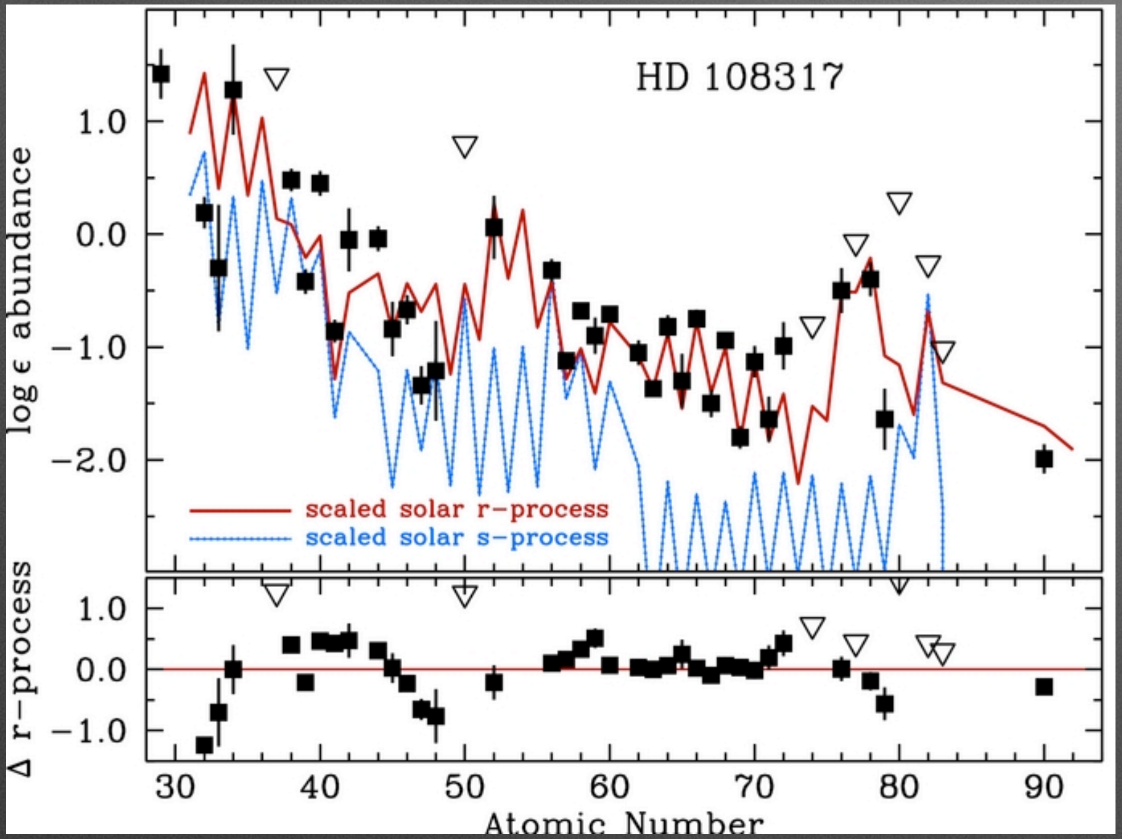
Different ejecta components will have different compositions and colors

Material with $Y_e \lesssim 0.23$ will experience strong *r*-process and be “red”

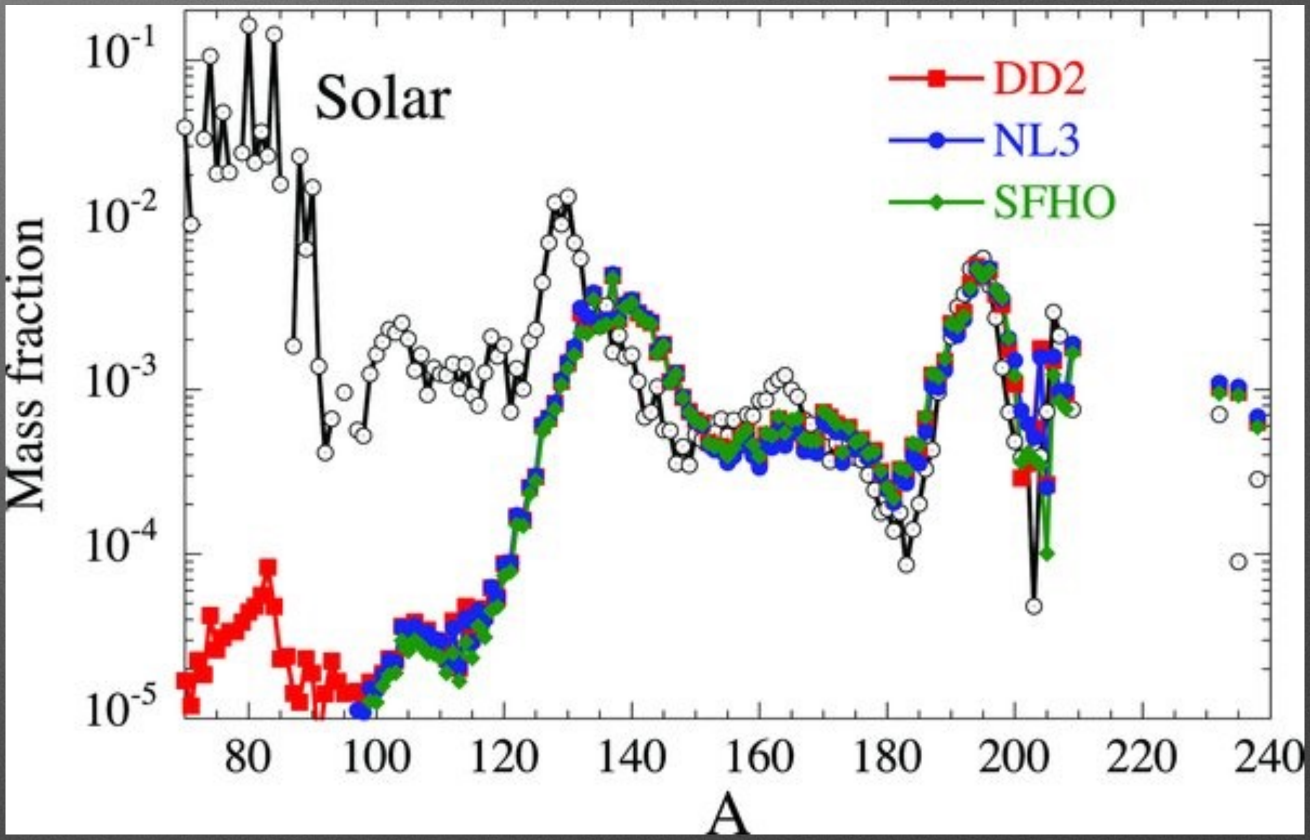


O. Korobkin, S. Rosswog,
A. Arcones, C. Winteler,
arXiv:1206.2379

r-process Nucleosynthesis

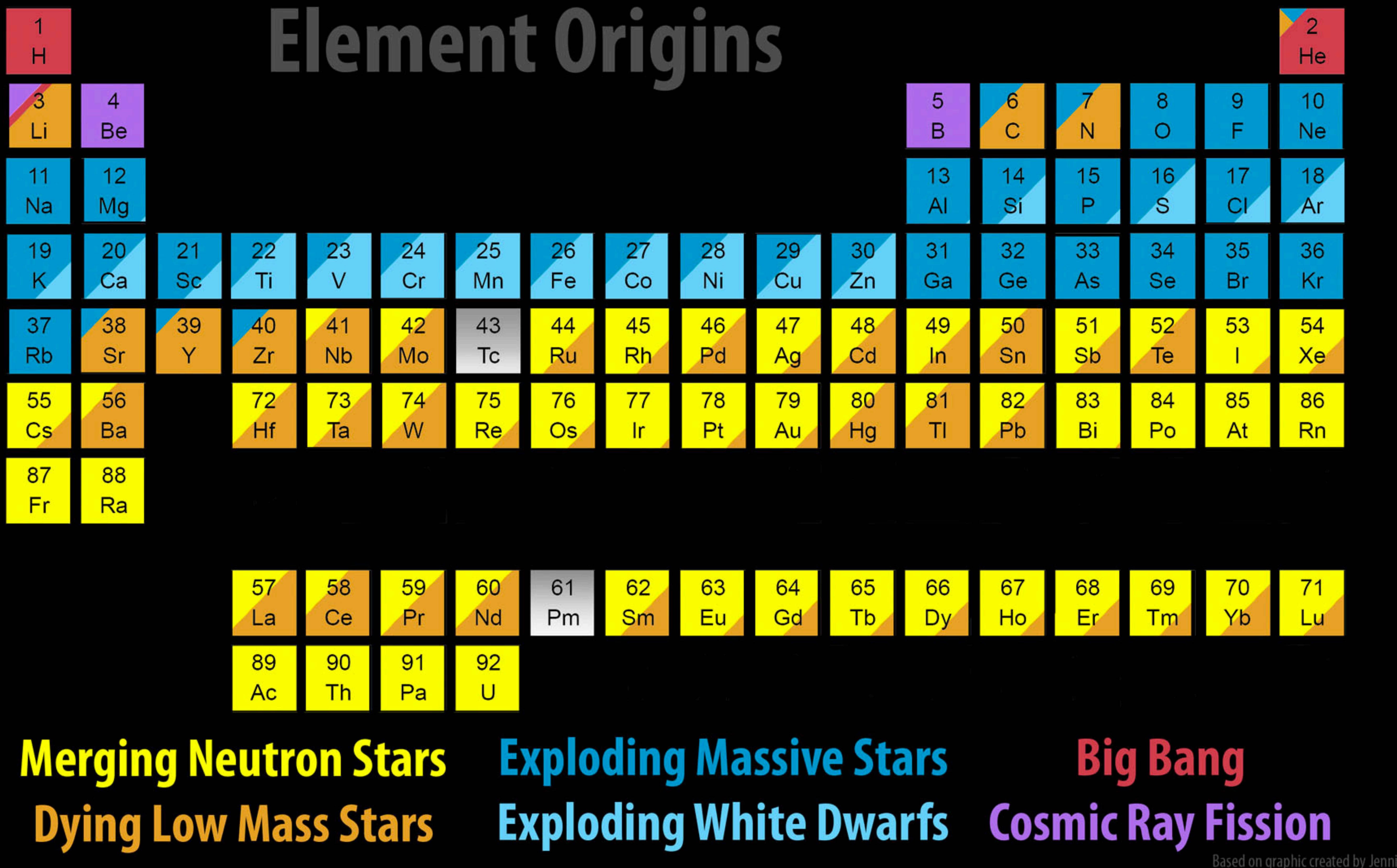


Roederer et al. 2014



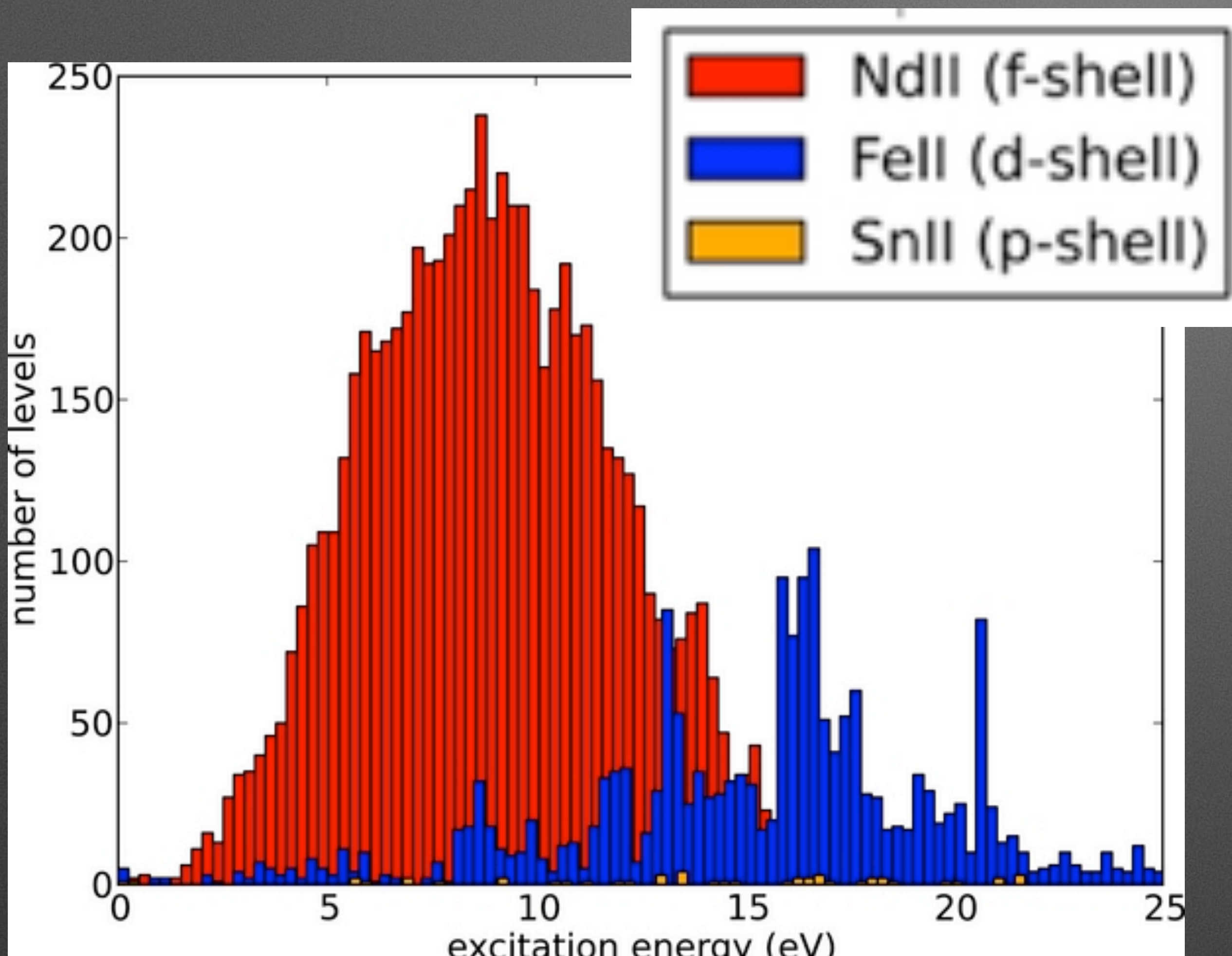
Bauswein et al. 2013

- Universal abundance ratios for “heavy” *r*-process, more scatter for the “light” *r*-process
- Mounting evidence that rare, high production events are responsible for the *r*-process
- Detailed BNS merger simulations reproduce the solar pattern



Credit: Jennifer Johnson/SDSS / CC BY 2.0 (modified)

This matters for the opacity



Kasen et al. 2013

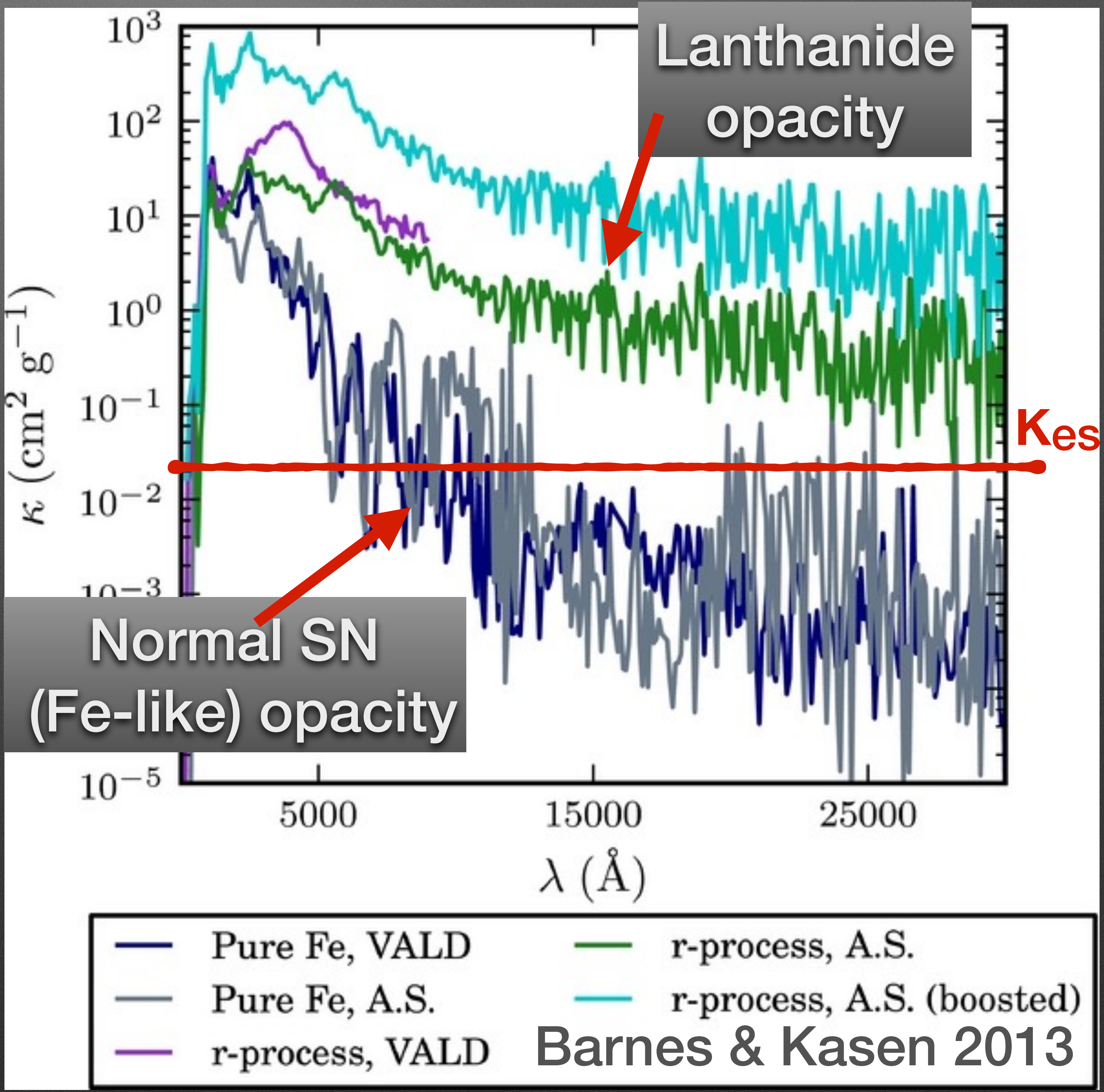
- Atoms/ions with open *f*-shells have many more available states compared to iron-peak elements

Ion	Configurations	Number of levels	Number of lines
Nd I	$\mathbf{4f^4 6s^2}$, $\mathbf{4f^4 6s(5d, 6p, 7s)}$, $\mathbf{4f^4 5d^2}$, $\mathbf{4f^4 5d6p}$, $4f^3 5d6s^2$, $4f^3 5d^2(6s, 6p)$, $4f^3 5d6s6p$	31,358	70,366,259

Tanaka et al. 2018

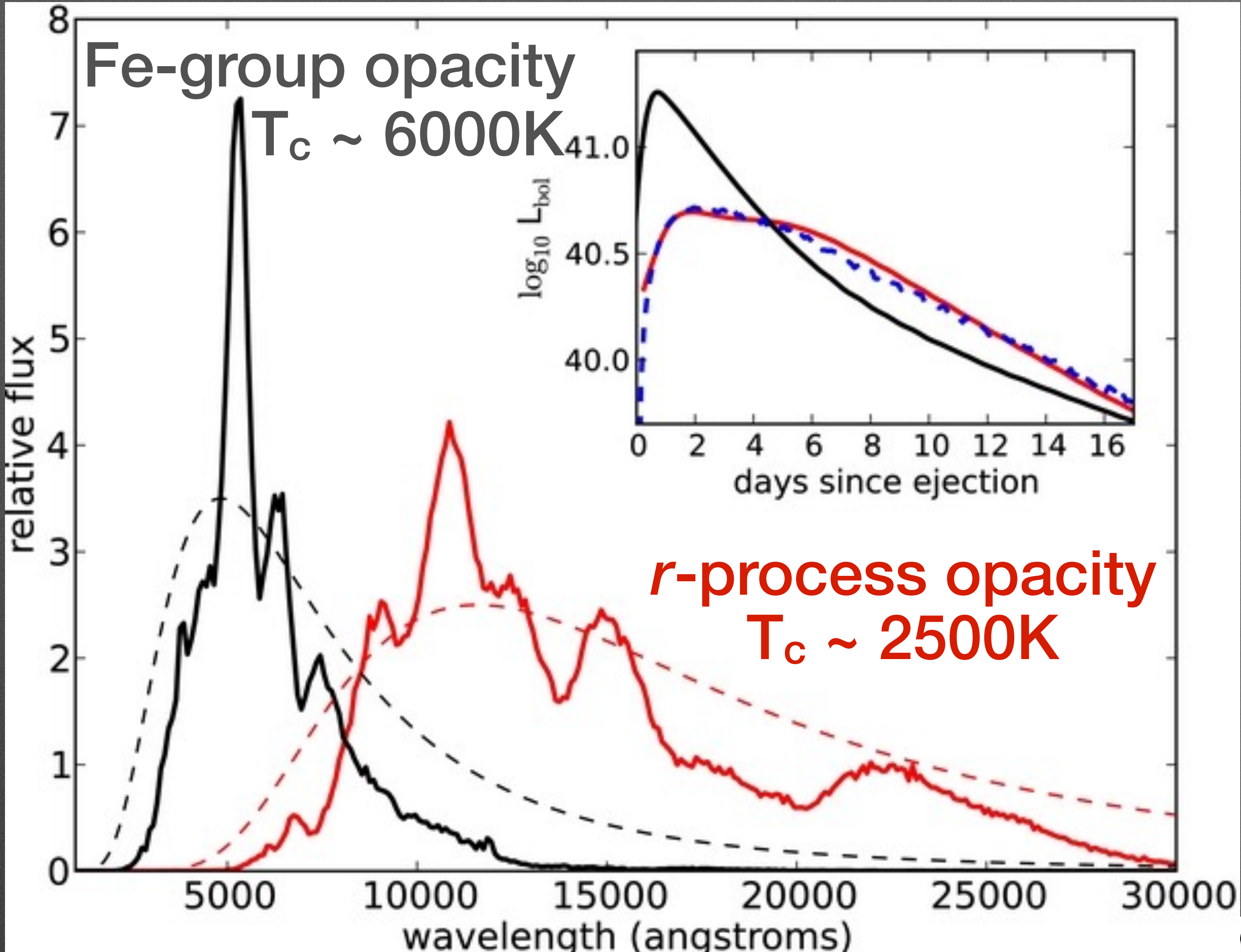
Ingredient #2: Expansion

- The effects of weak lines are greatly enhanced in material with strong velocity gradients



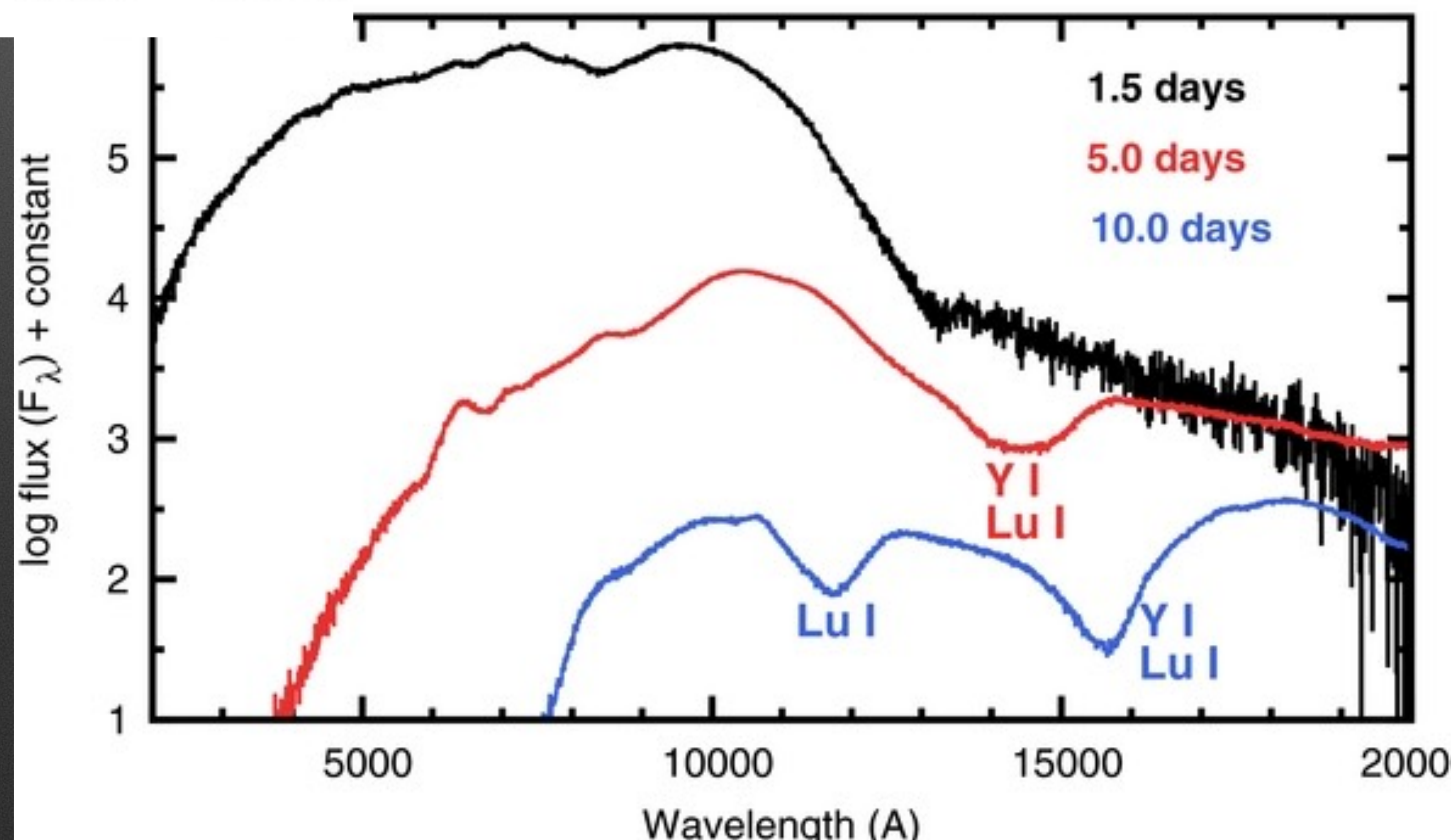
Barnes & Kasen 2013

Initial models



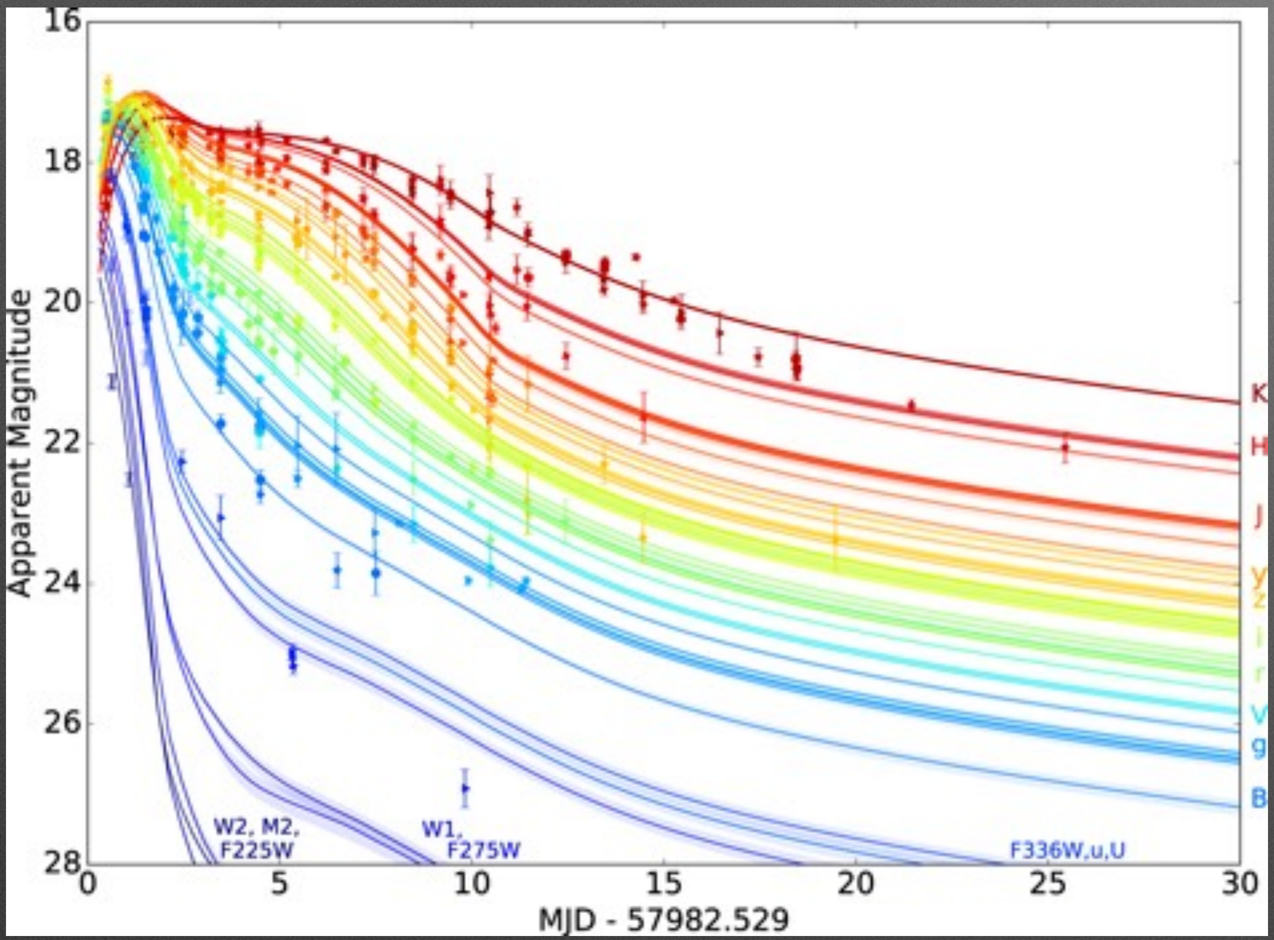
Kasen, Badnell, & Barnes 2013

Tanaka & Hotokezaka 2013

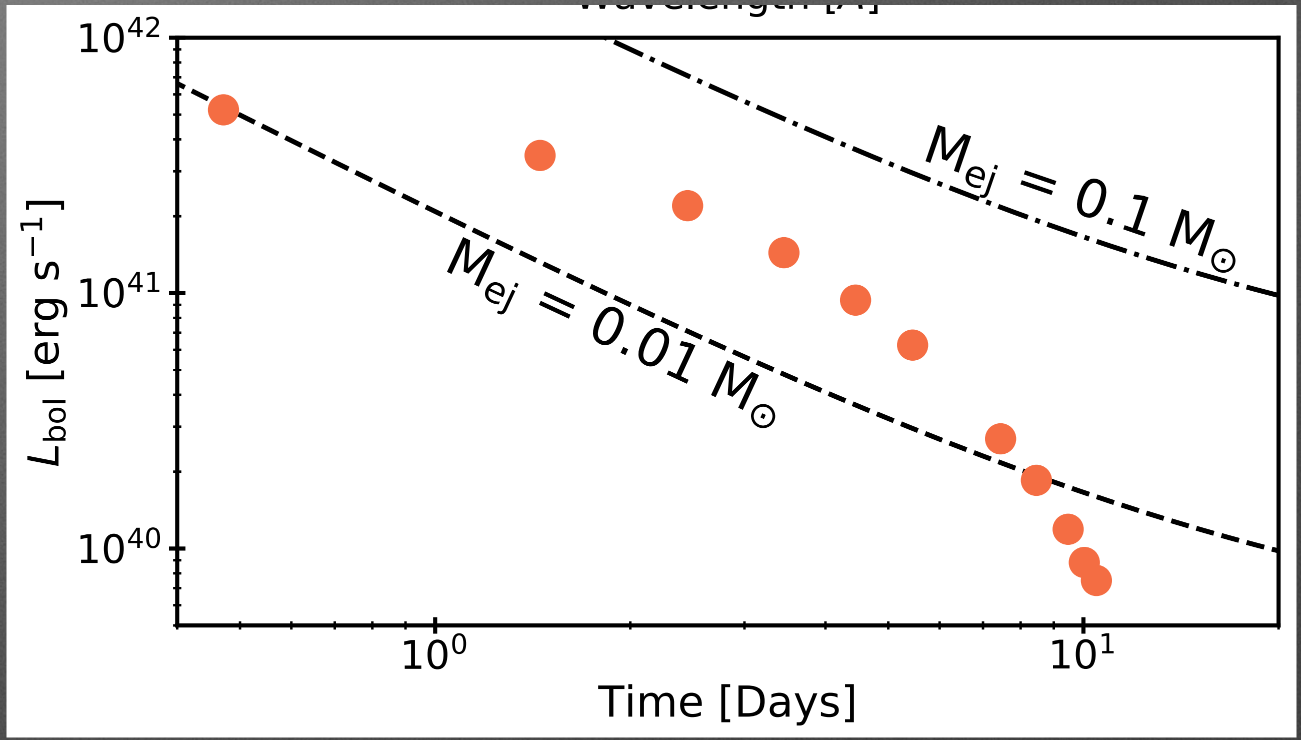


- The first KN models using enhanced *r*-process opacities (from 2013) showed a shift of flux to the NIR

Basic Observations of GW170817



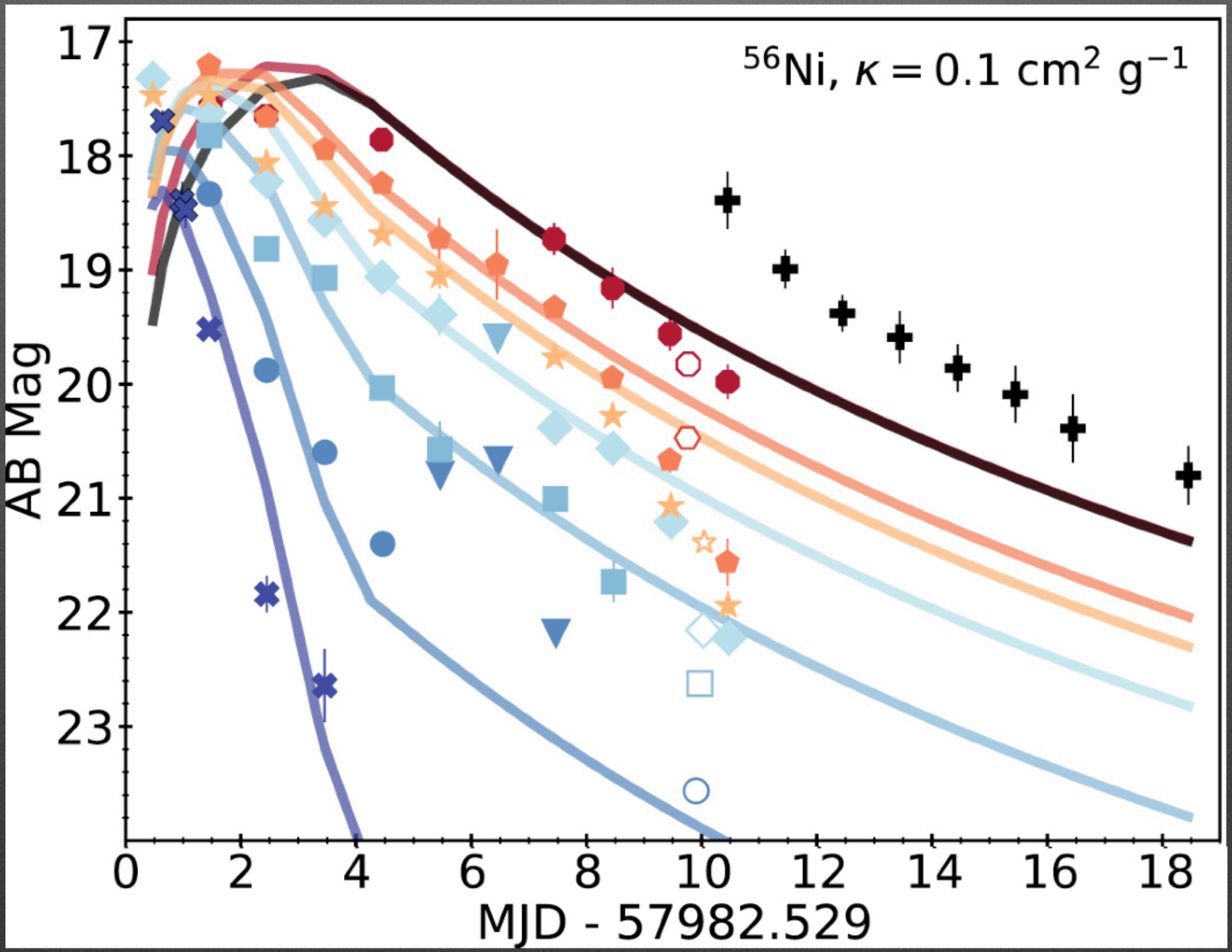
Villar et al. 2017



Cowperthwaite et al. 2017

- Very fast fading in blue, slower in near-IR
- Color temperature of ~2500K after a week
- Luminosity/timescale consistent with ~few×10^{-2} M$_\odot$ of *r*-process ejecta

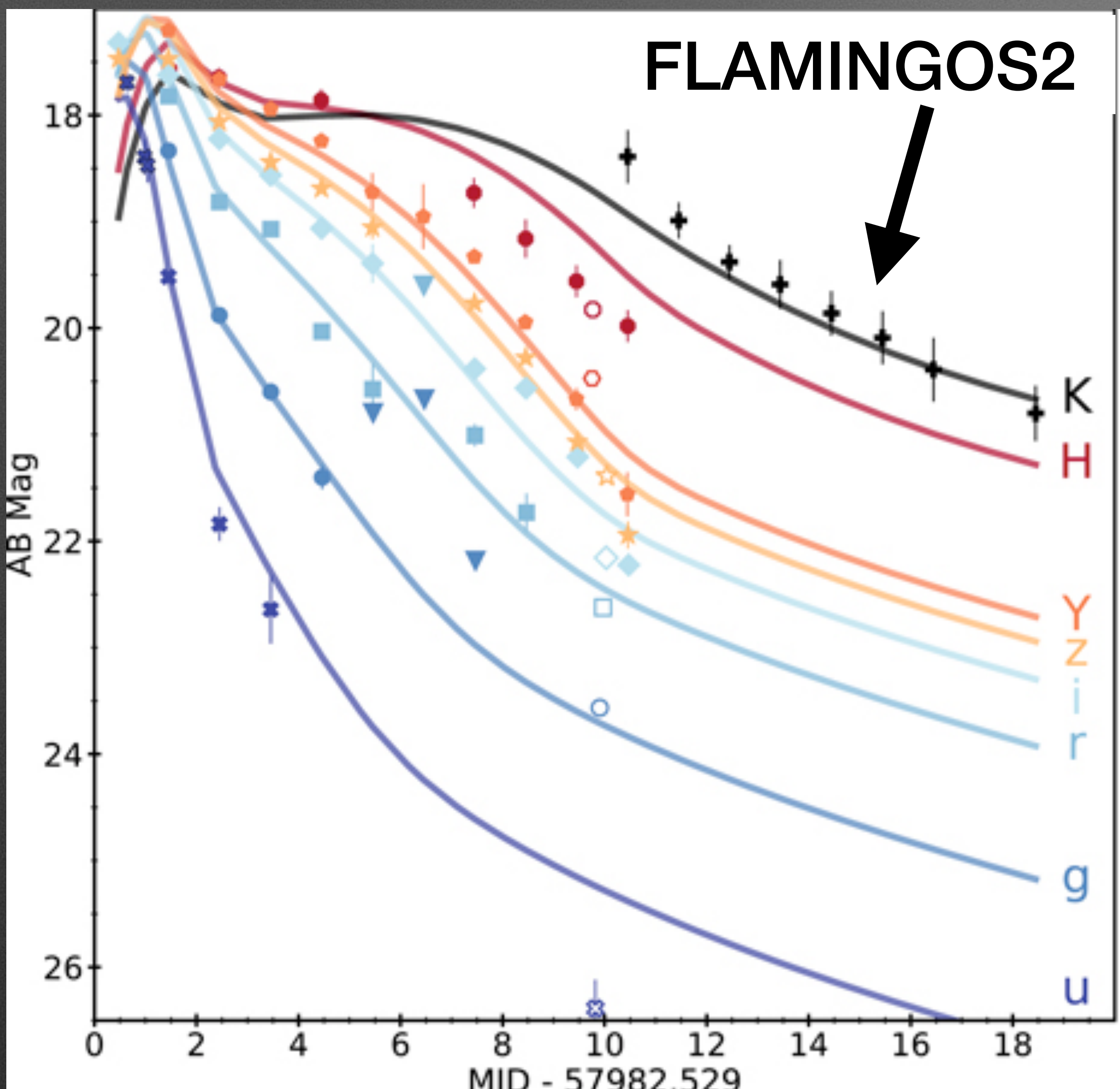
Light curve fits



Cowperthwaite et al. 2017

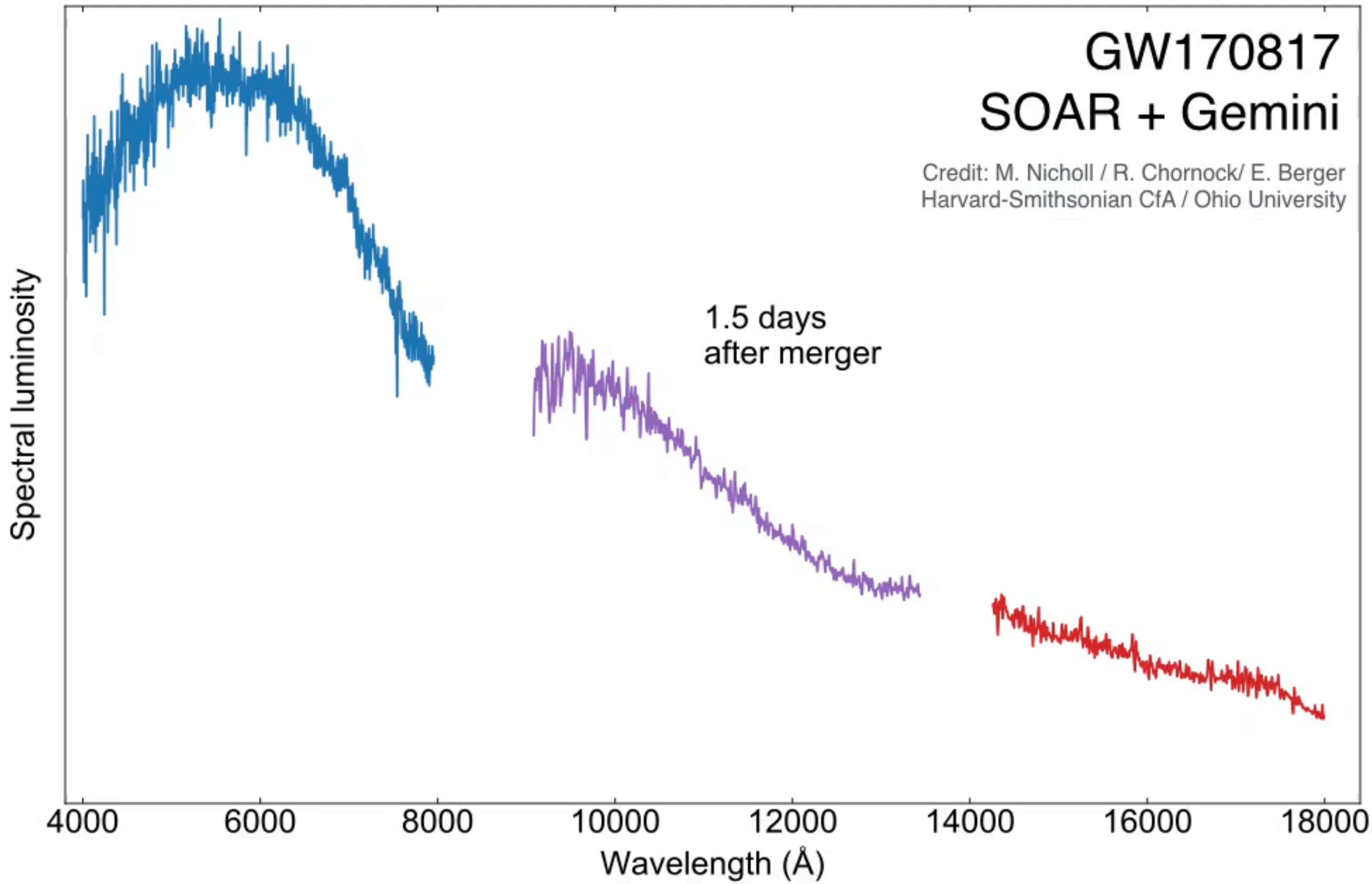
Normal SN material does not provide a good fit to the light curve shape or match the spectra and NIR excess

Kilonova fits



Cowperthwaite et al. 2017;
Villar et al. 2017

- Best-fit model has two components
  - Low opacity "blue" kilonova with ~0.01-0.02 $M_{\odot}$ and v~0.25c that dominates in optical at early times
  - High opacity "red" kilonova component has ~0.04 $M_{\odot}$ and v~0.1c that peaks in the NIR on longer timescales


GW170817
SOAR + Gemini
Credit: M. Nicholl / R. Chornock/ E. Berger
Harvard-Smithsonian CfA / Ohio University
1.5 days
after merger
Spectral luminosity
4000
6000
8000
10000
12000
14000
16000
18000
Wavelength (Å)

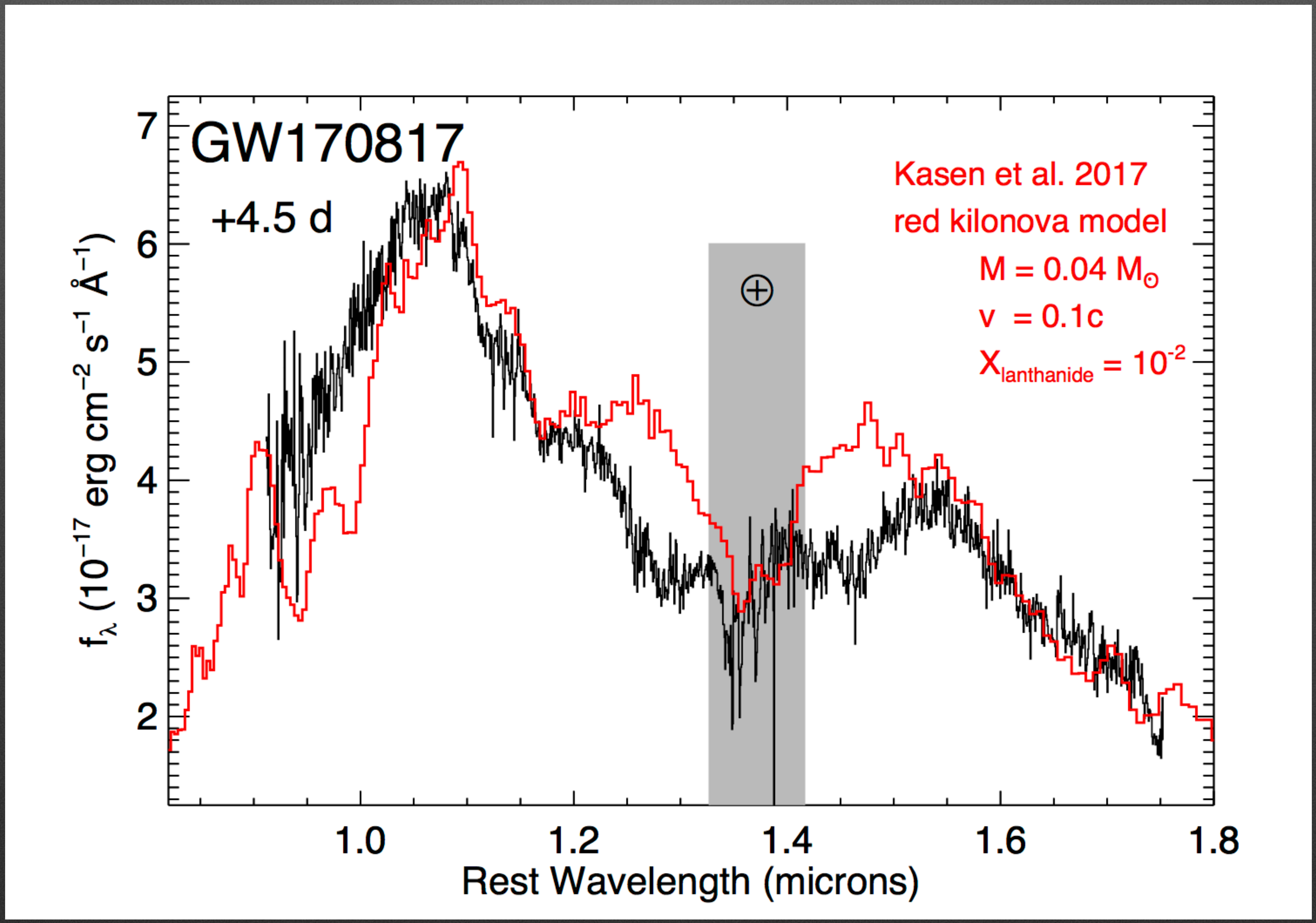
Evidence for *r*-process

1. That there was anything at all to see in the optical/NIR!

    - Some models now invoke other sources of heating at early times for the “blue” emission (e.g., shocks), but all still agree that the long-lasting IR emission requires some input heating from radioactive decay

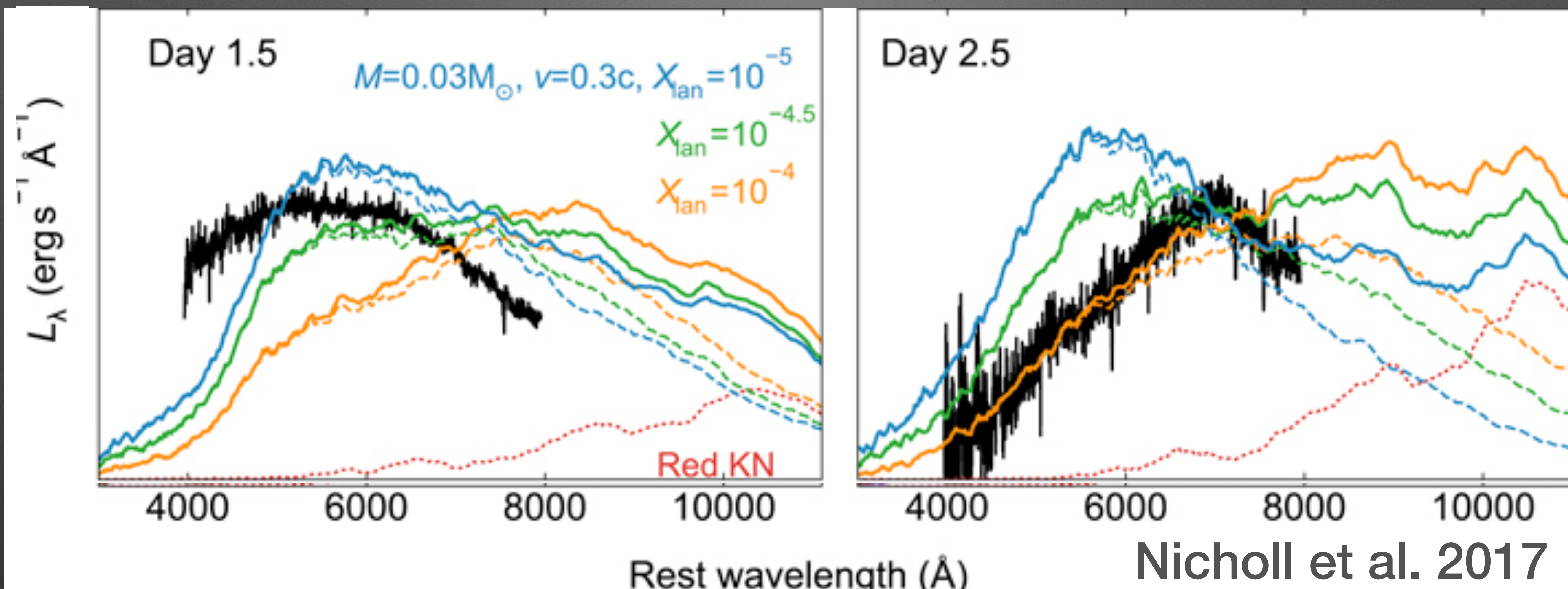
2. Spectral energy distribution peaks near ~1 micron are a consequence of lanthanide opacity

Amazing NIR Agreement!



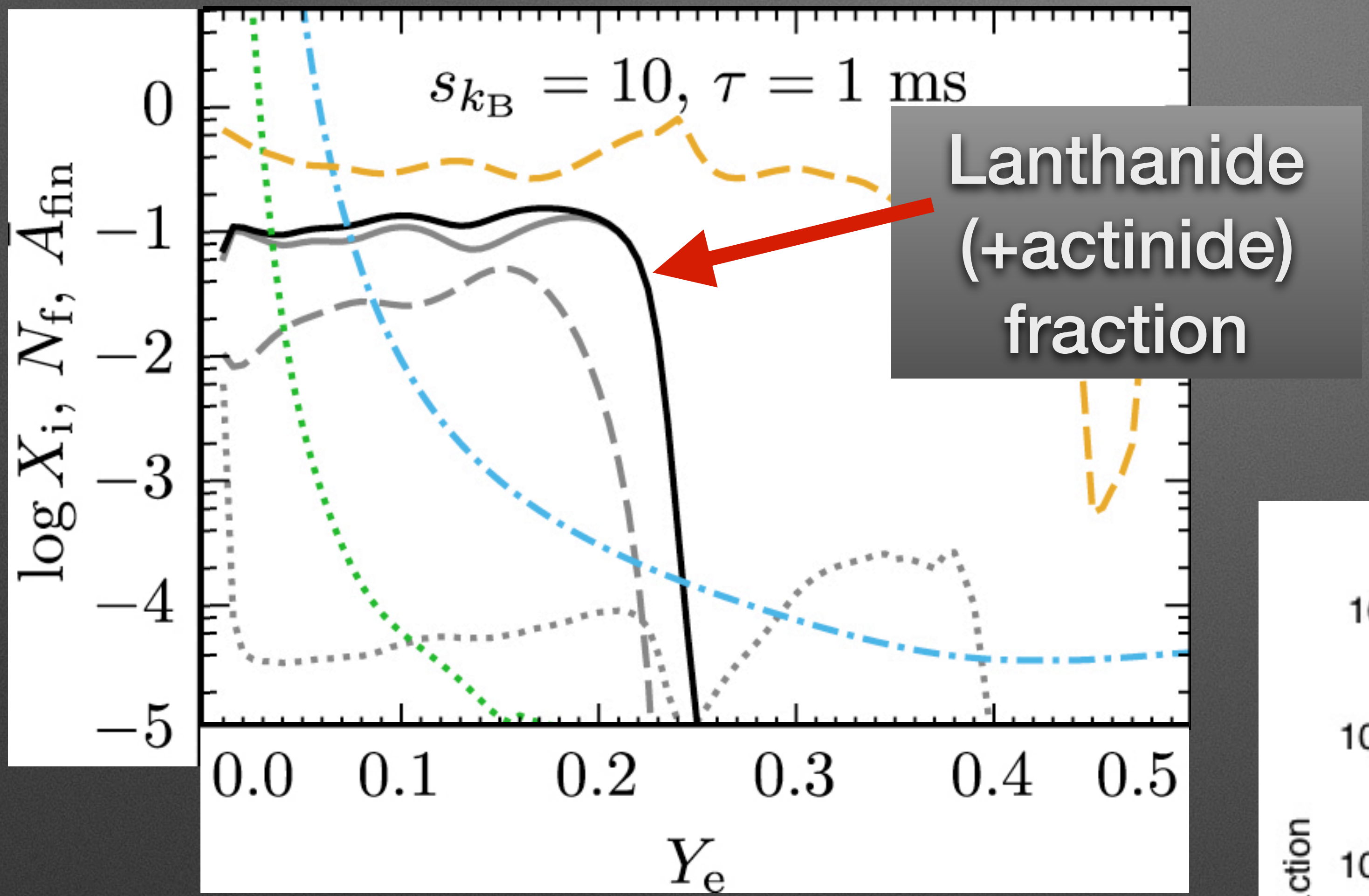
Chornock et al. 2017

Blue kilonova

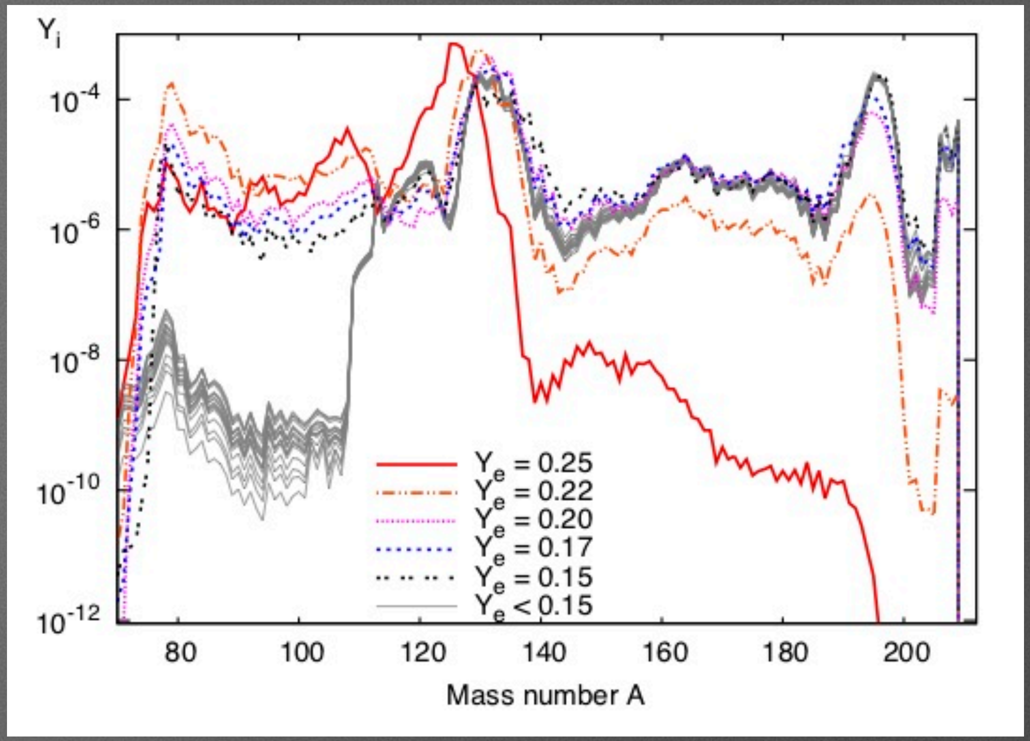


- The blue kilonova component can only accommodate light *r*-process (much lower lanthanide abundances)
- But the velocities are very high (~0.3c)

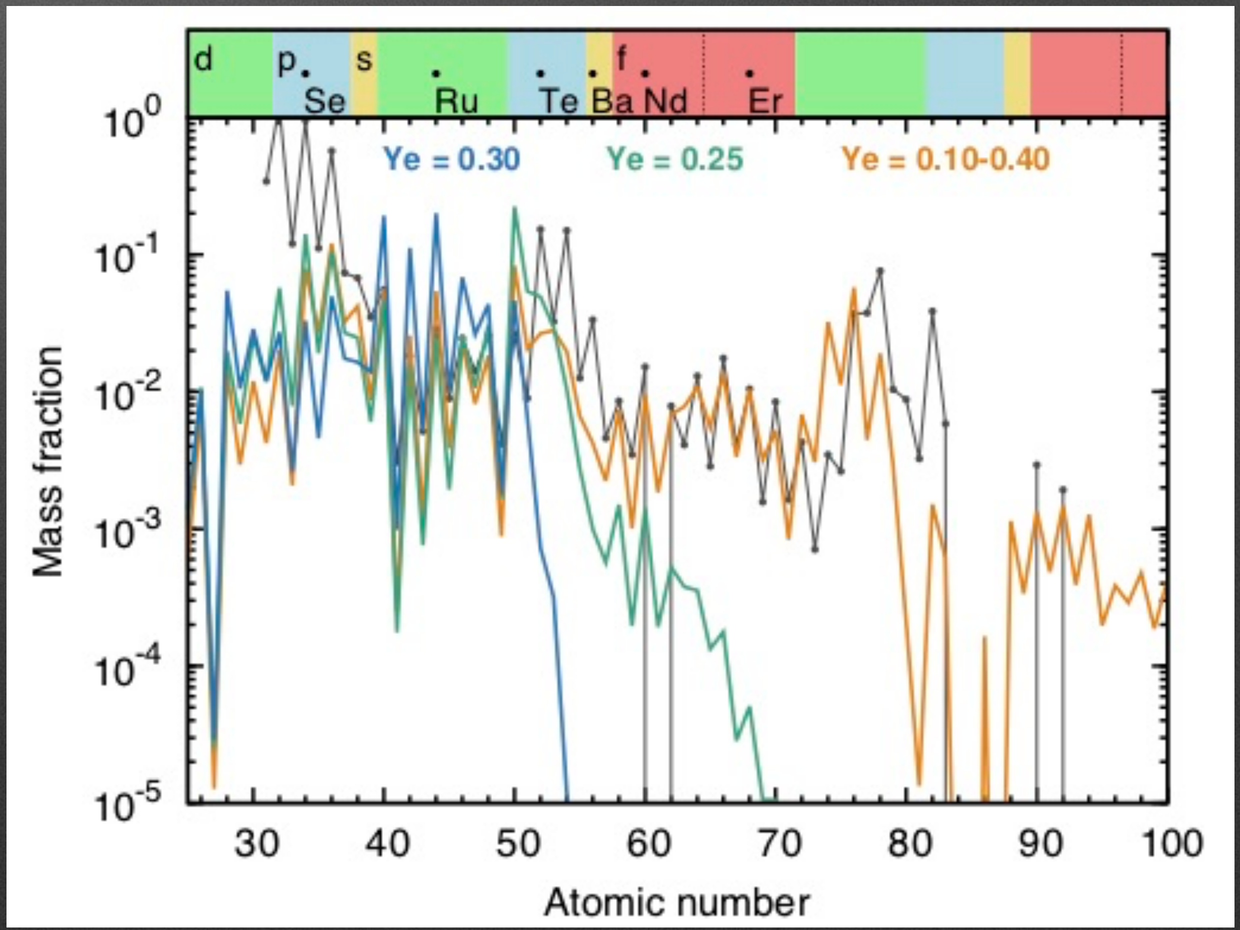
Nucleosynthesis



Lippuner & Roberts 2015



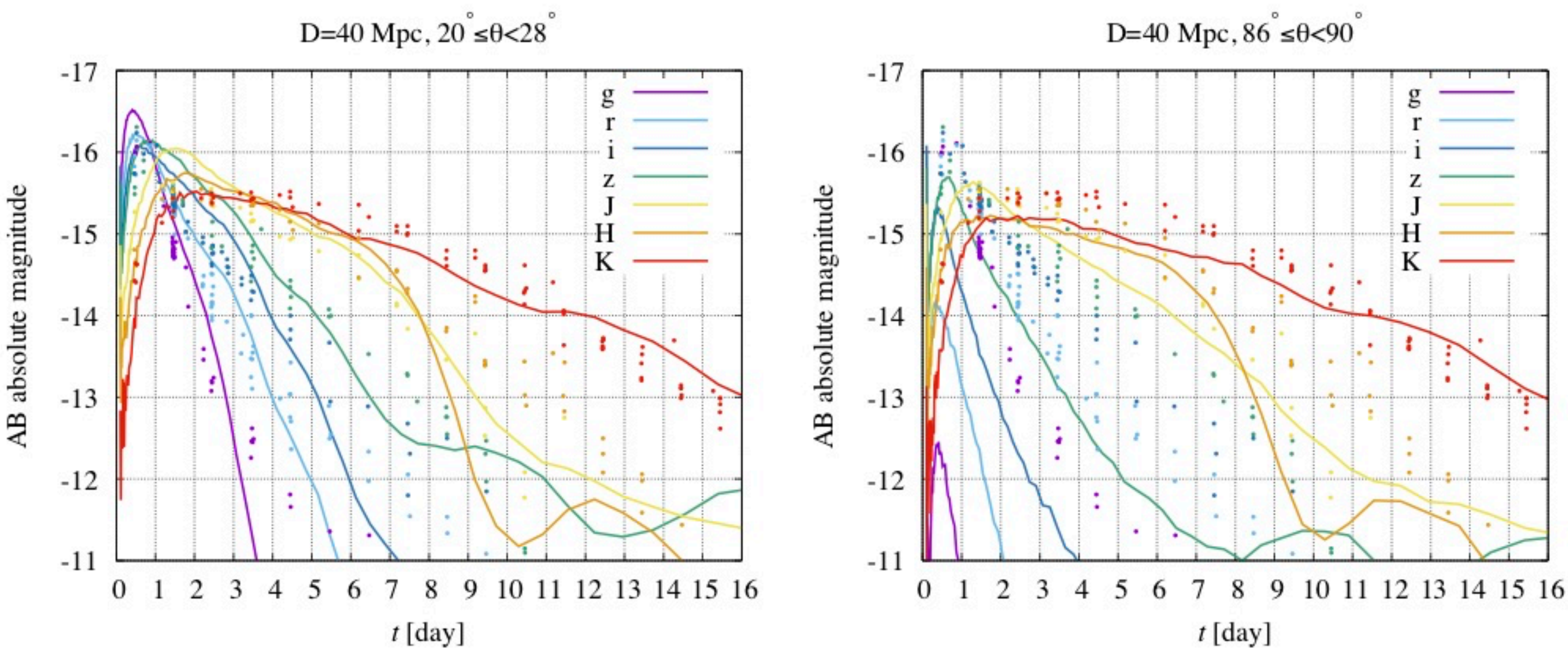
Korobkin et al. 2012



Tanaka et al. 2018

- There is a production threshold below Y_e~0.23 in merger calculations: lanthanide fraction is not really a free knob

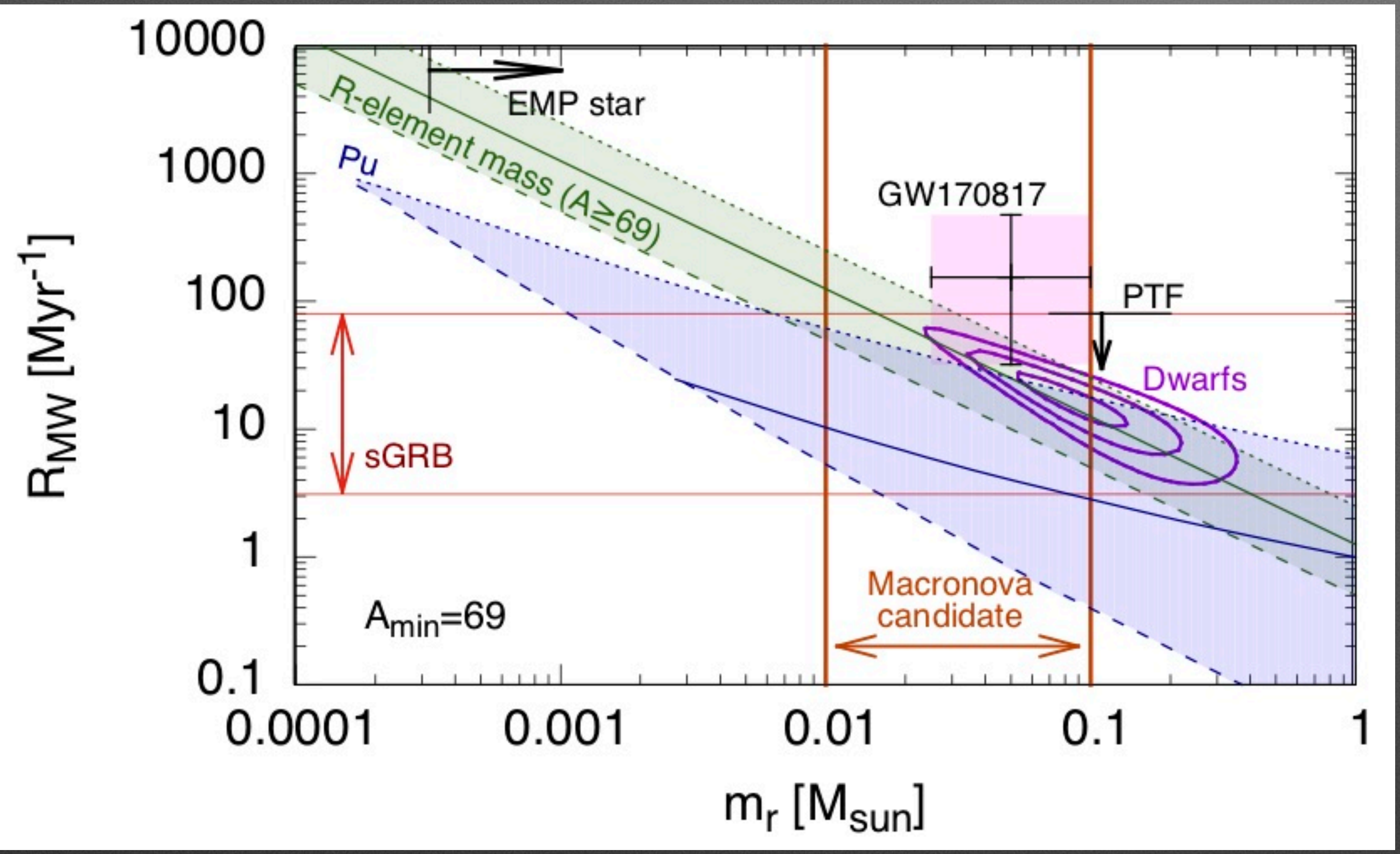
2D kilonova simulations



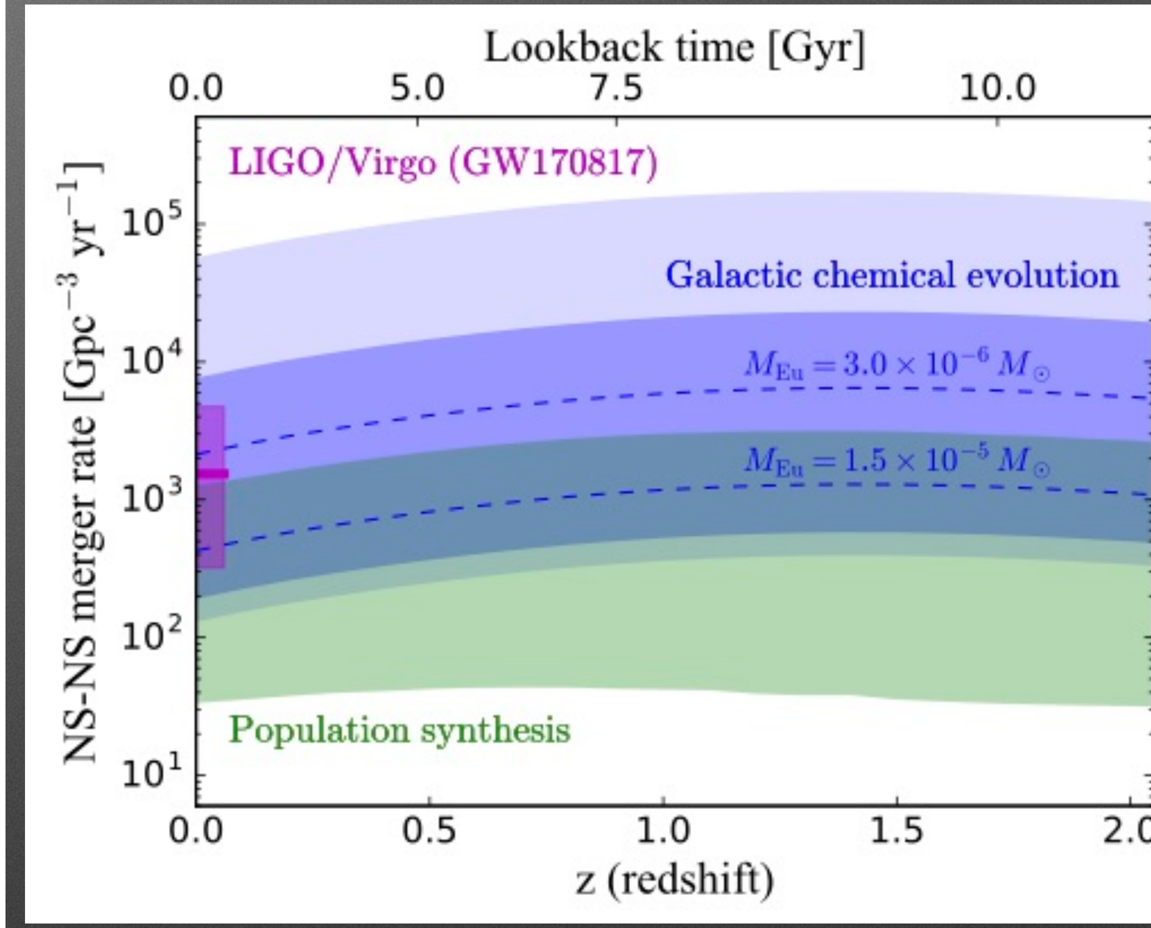
Kawaguchi et al. 2018

- Reprocessing of one component by another may be very important, as is the fundamentally aspherical nature of the kilonova

Galactic nucleosynthesis



Hotokezaka et al. 2018



Côté et al. 2018

- With order-of-magnitude uncertainties, the *r*-process production in this event is about right to generate MW abundances

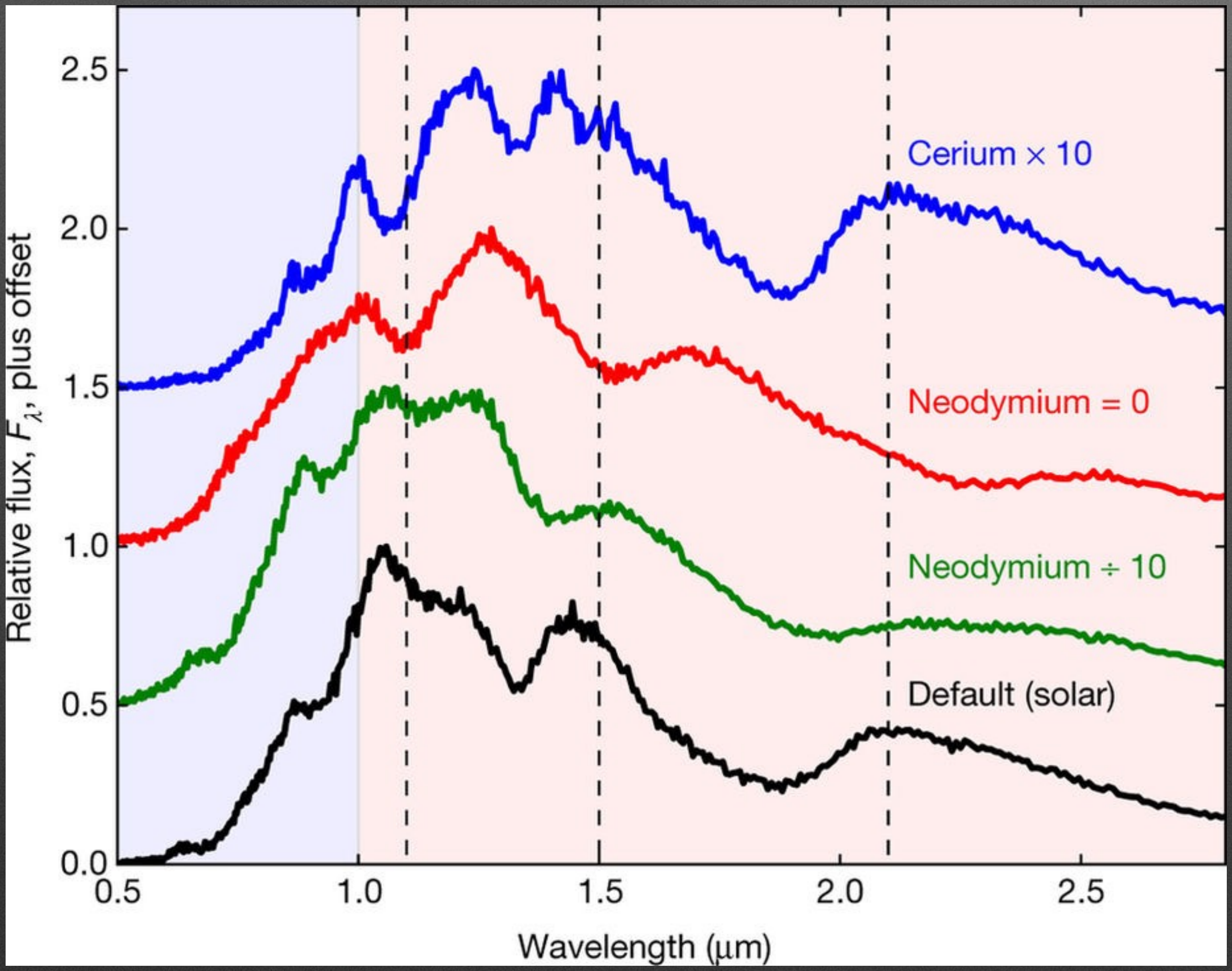
Present & Future

- Binary neutron star mergers produce a range of ejecta material with various compositions and velocities
- Optical and NIR observations are sensitive to different components of the ejecta
  - Spectroscopy is key, although many theoretical uncertainties in the interpretation
- What is the range of kilonova properties?
  - Intrinsic (Range of ejecta masses, nucleosynthetic outputs)
  - Extrinsic (viewing angle)
- Rapid ToO observations with Gemini will be a valuable part of this future
- Thanks to everybody at the observatory for all the work to obtain the observations of GW170817, pointing into the setting sun at twilight and up to airmass 3 for three weeks

NSF/LIGO/Sonoma State University/A. Simonnet

Backup slides

Can we actually constrain detailed abundances?



Kasen et al. 2017

- Maybe?
- In the future?