

Multi-Messenger Counterparts

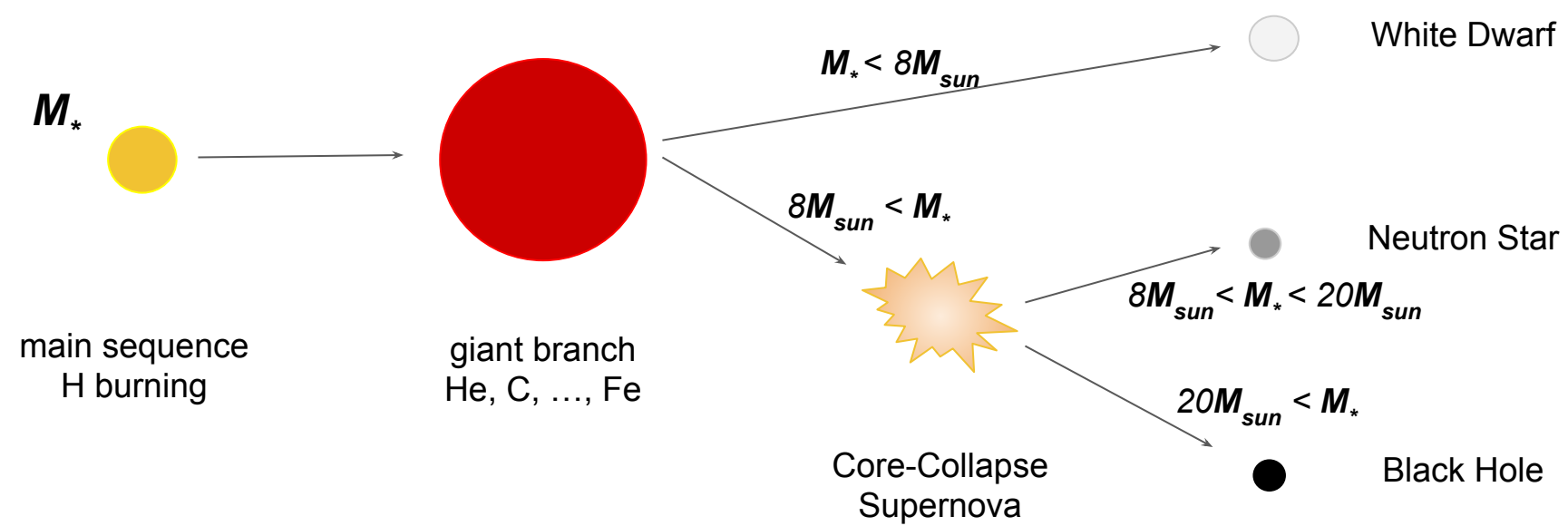
Reed Clasey Essick
KICP

2 November 2019
Compton Lectures
University of Chicago

<https://github.com/reedessick/compton-lectures-2019>

Review: Stellar Evolution

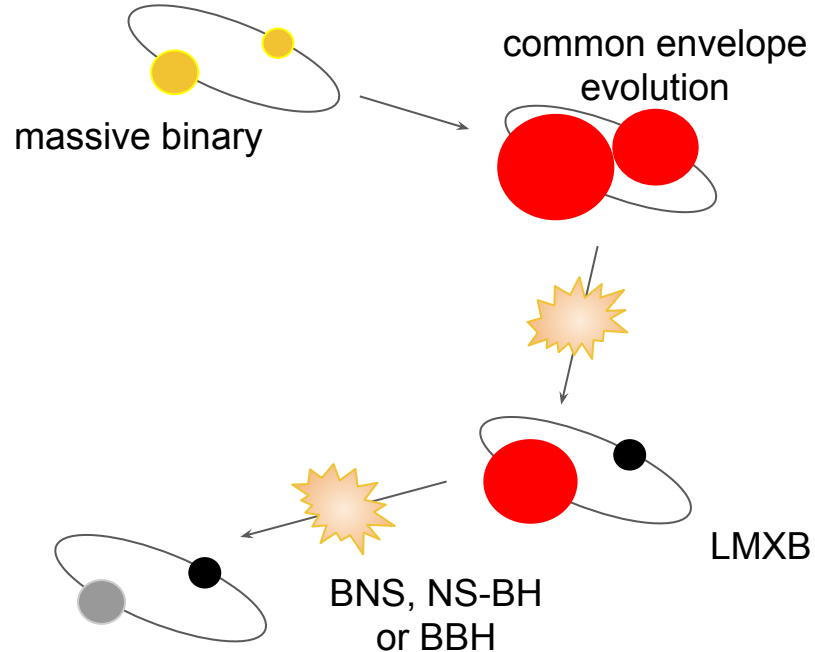
Neutron Stars and **Black Holes** are the end states of massive stars



Review: Stellar Evolution

Binaries containing **Compact Objects** form through

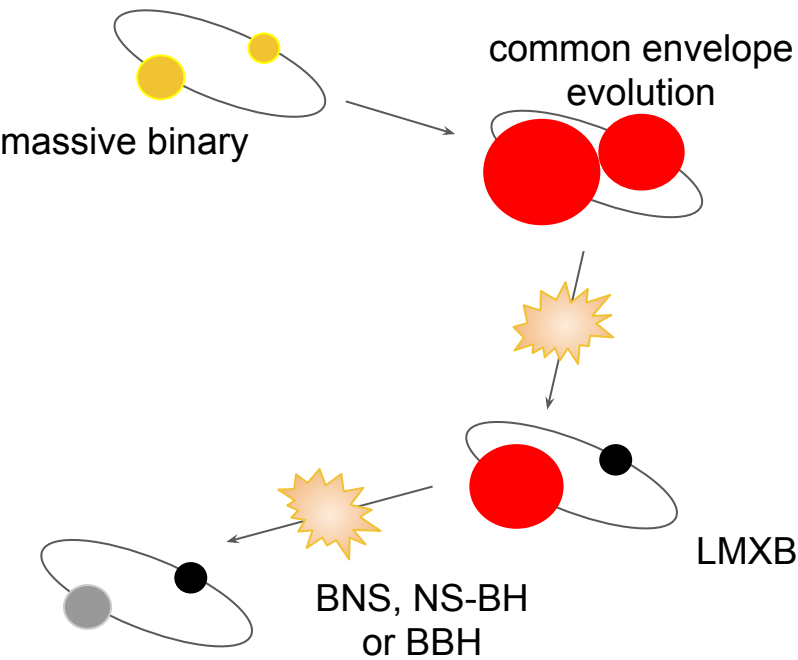
isolated evolution



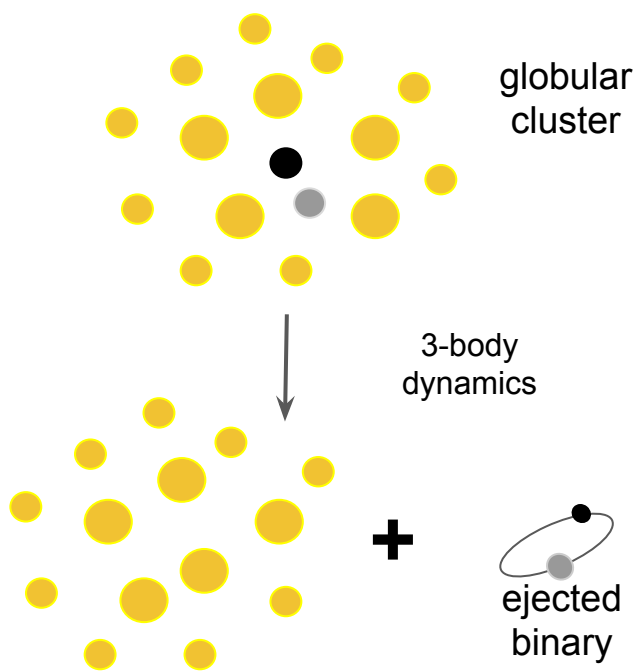
Review: Stellar Evolution

Binaries containing **Compact Objects** form through

isolated evolution



dynamical capture



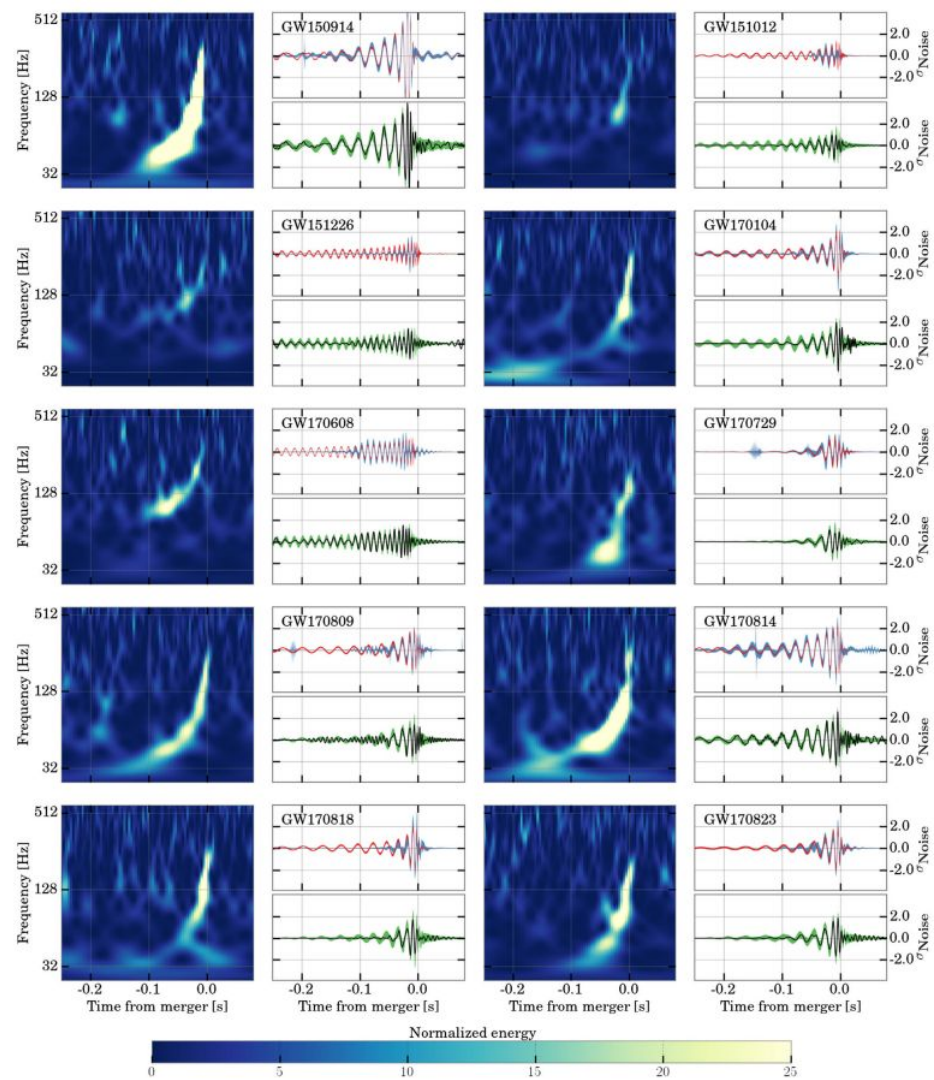
Review: Populations

We have detected 10 binary Black Hole (BBH) and one binary Neutron Star system (BNS) coalescences in the first two observing runs

- O1: Sep 2015 - Jan 2016
- O2: Dec 2016 - Aug 2017

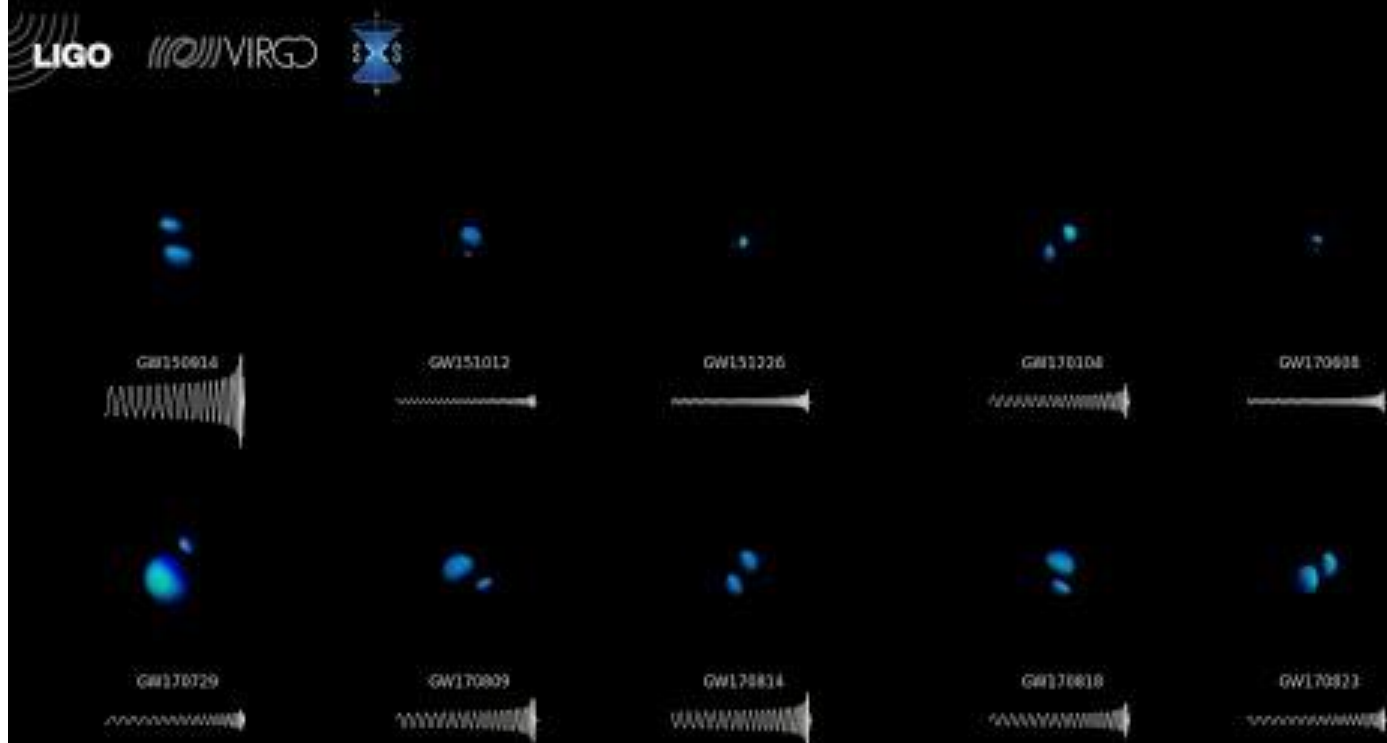
and the third observing run is currently on-going!

- O3: Apr 2019 - Apr 2020



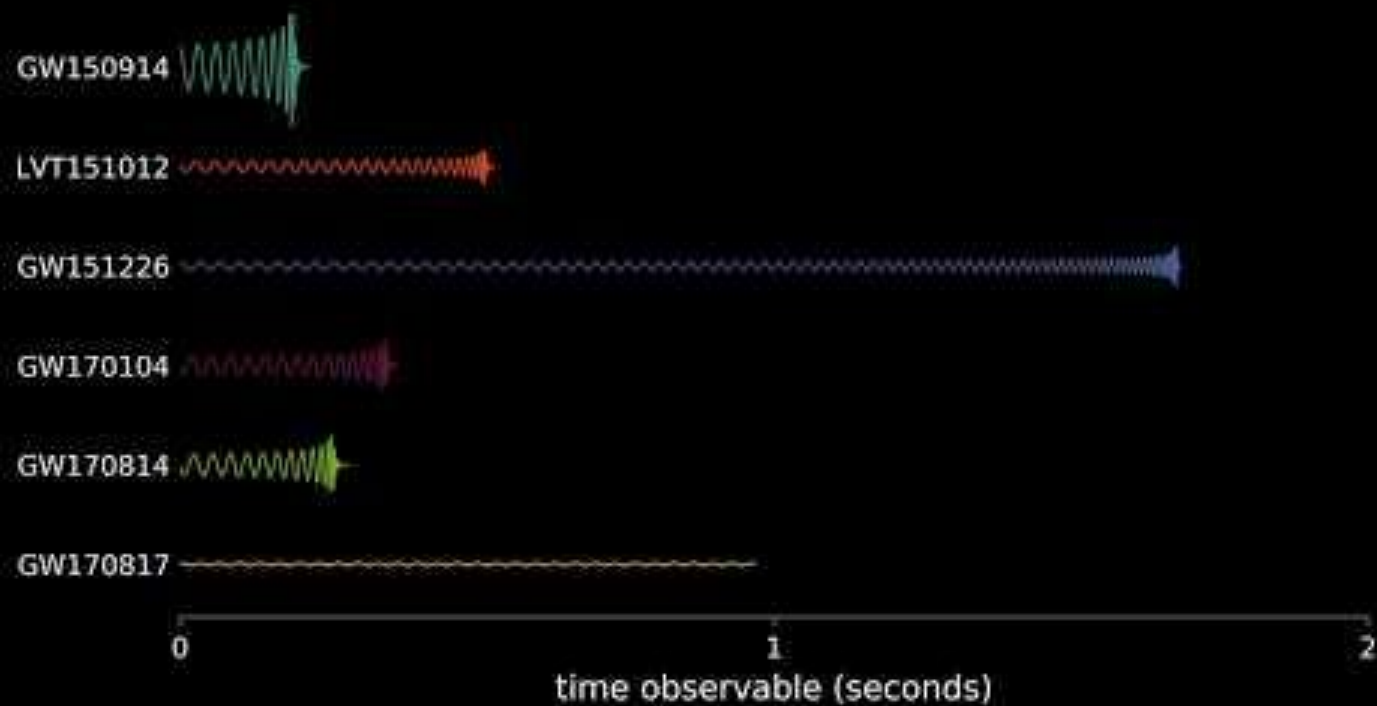
Review

Populations



Review

Populations



Multi-messenger astronomy

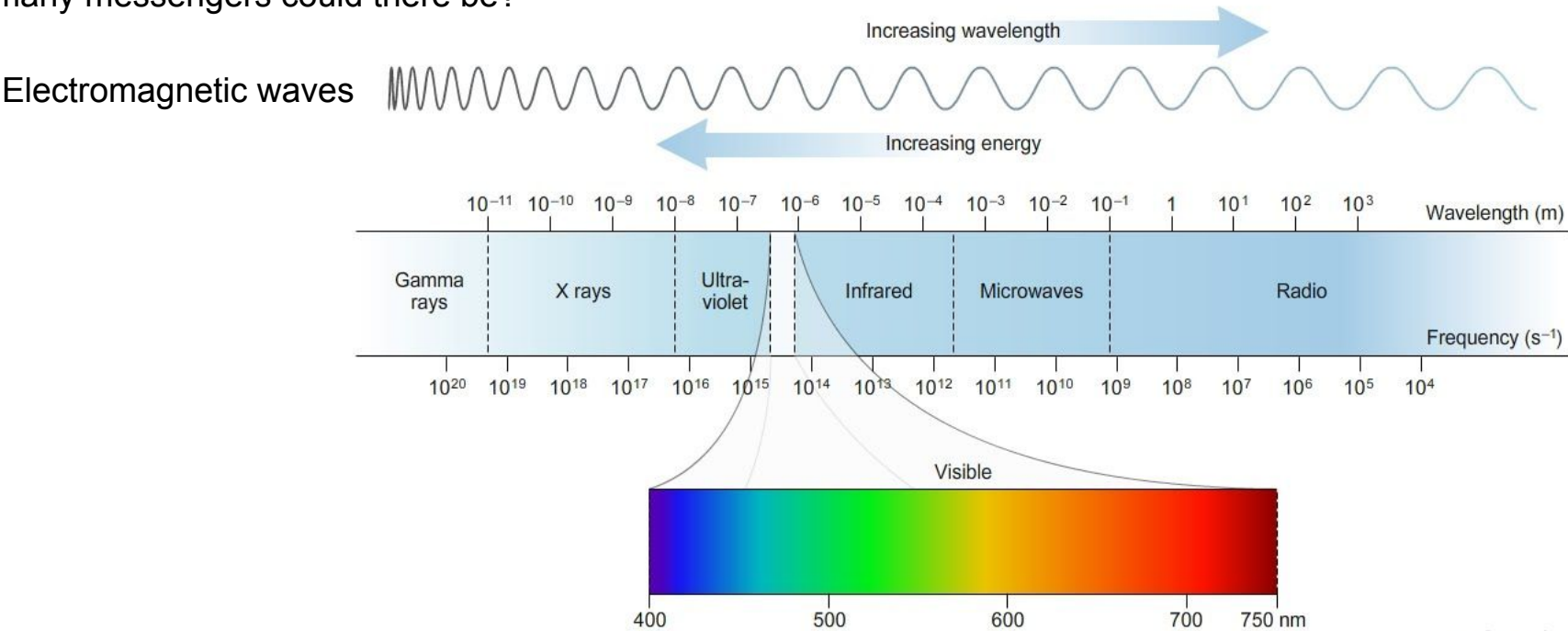
- What does this mean?

Multi-messenger astronomy

- What does this mean?
- How many messengers could there be?

Multi-messenger astronomy

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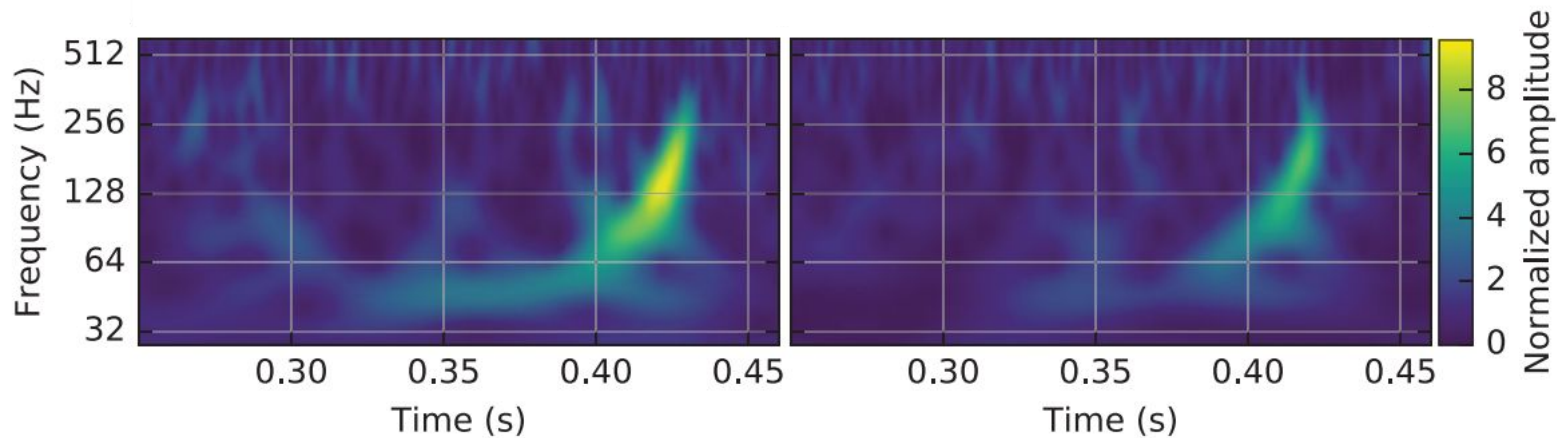


Multi-messenger astronomy

- What does this mean?
- How many messengers could there be?

Electromagnetic waves

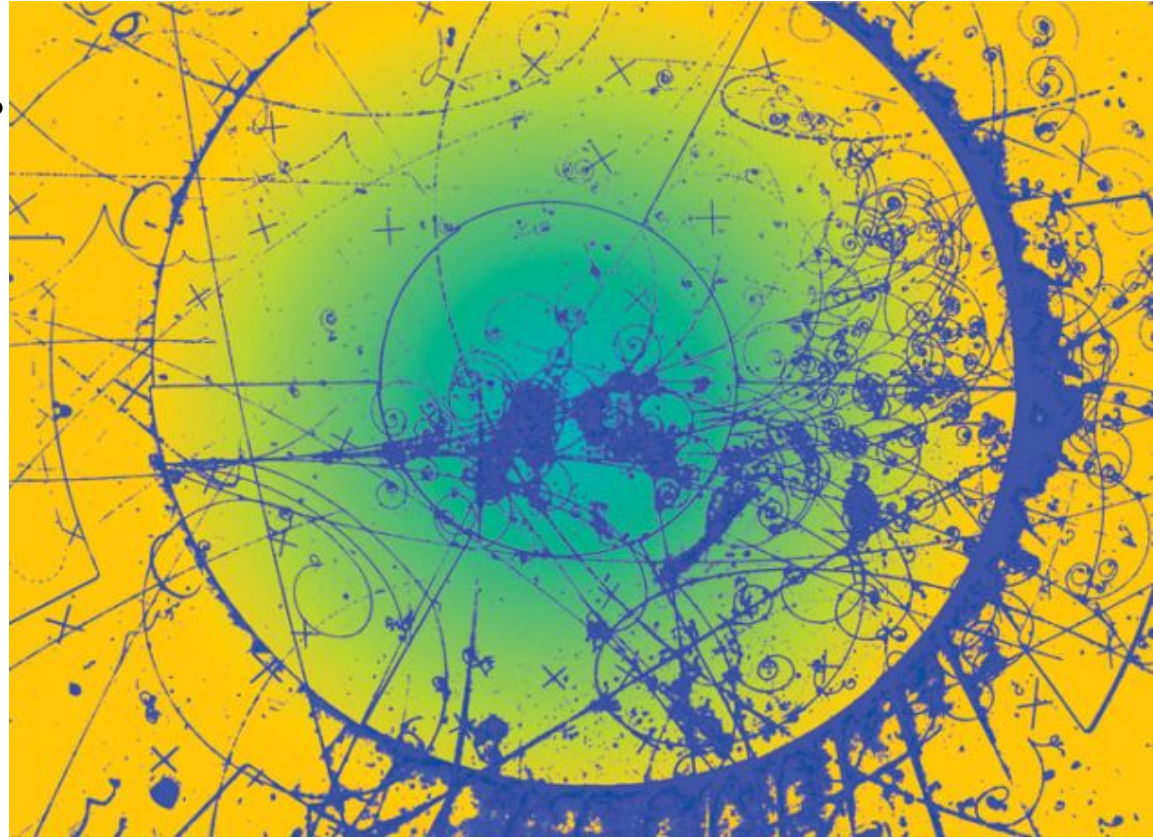
Gravitational waves



Multi-messenger astronomy

- What does this mean?
- How many messengers could there be?

Electromagnetic waves
Gravitational waves
Neutrinos



Multi-messenger astronomy

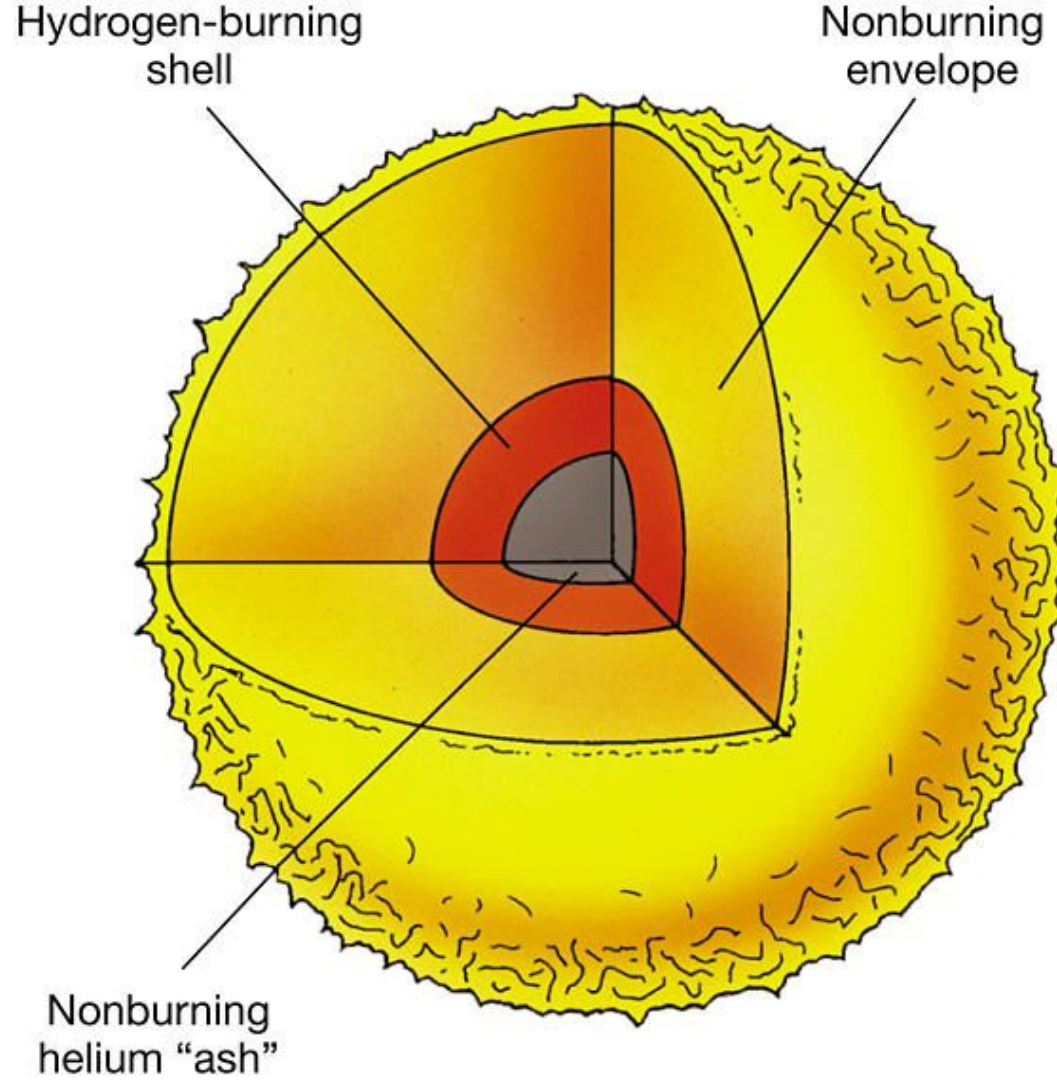
- What does this mean?
- How many messengers could there be?
- What kinds of detectors do we have for each type of messenger?

Electromagnetic waves

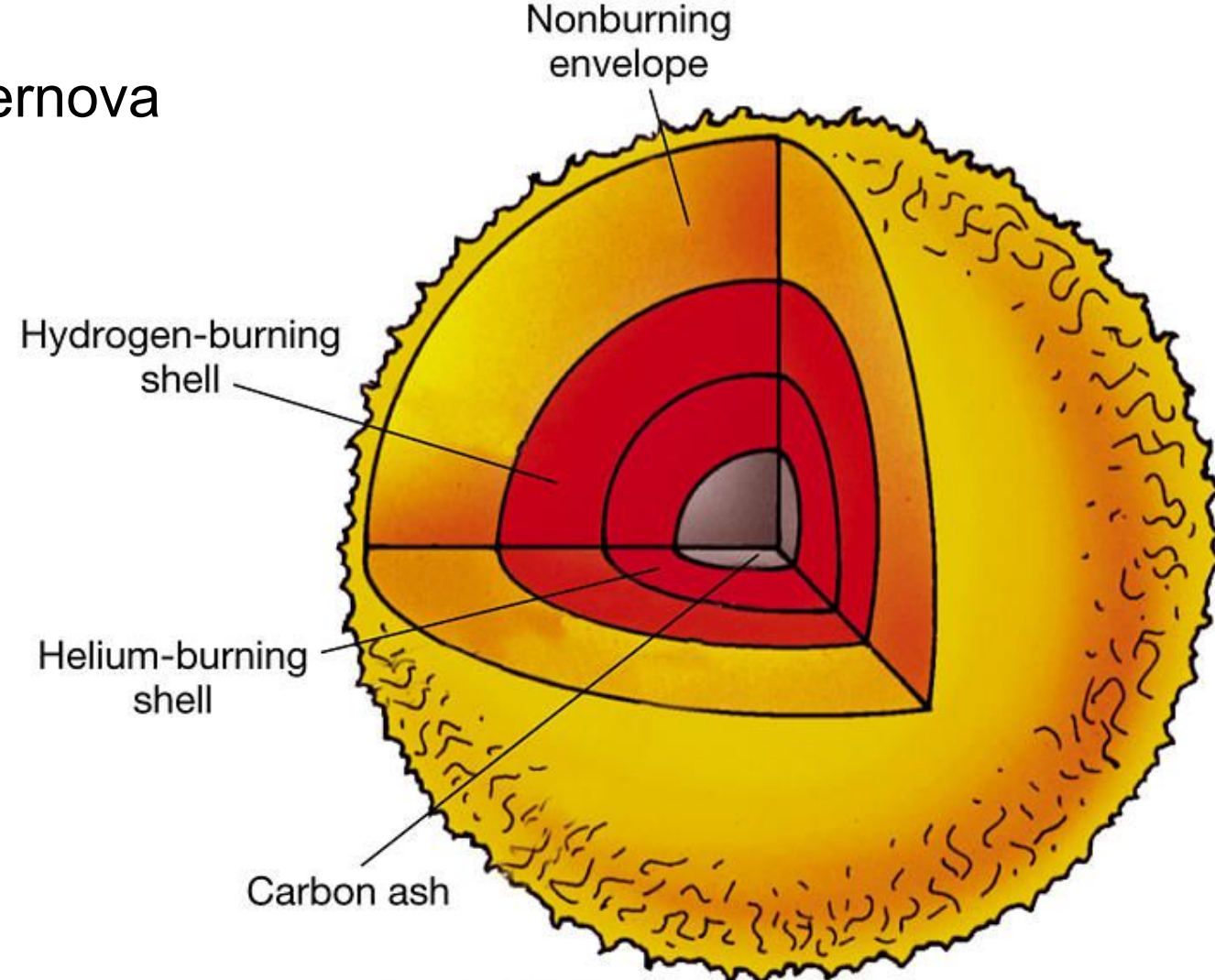
Gravitational waves

Neutrinos

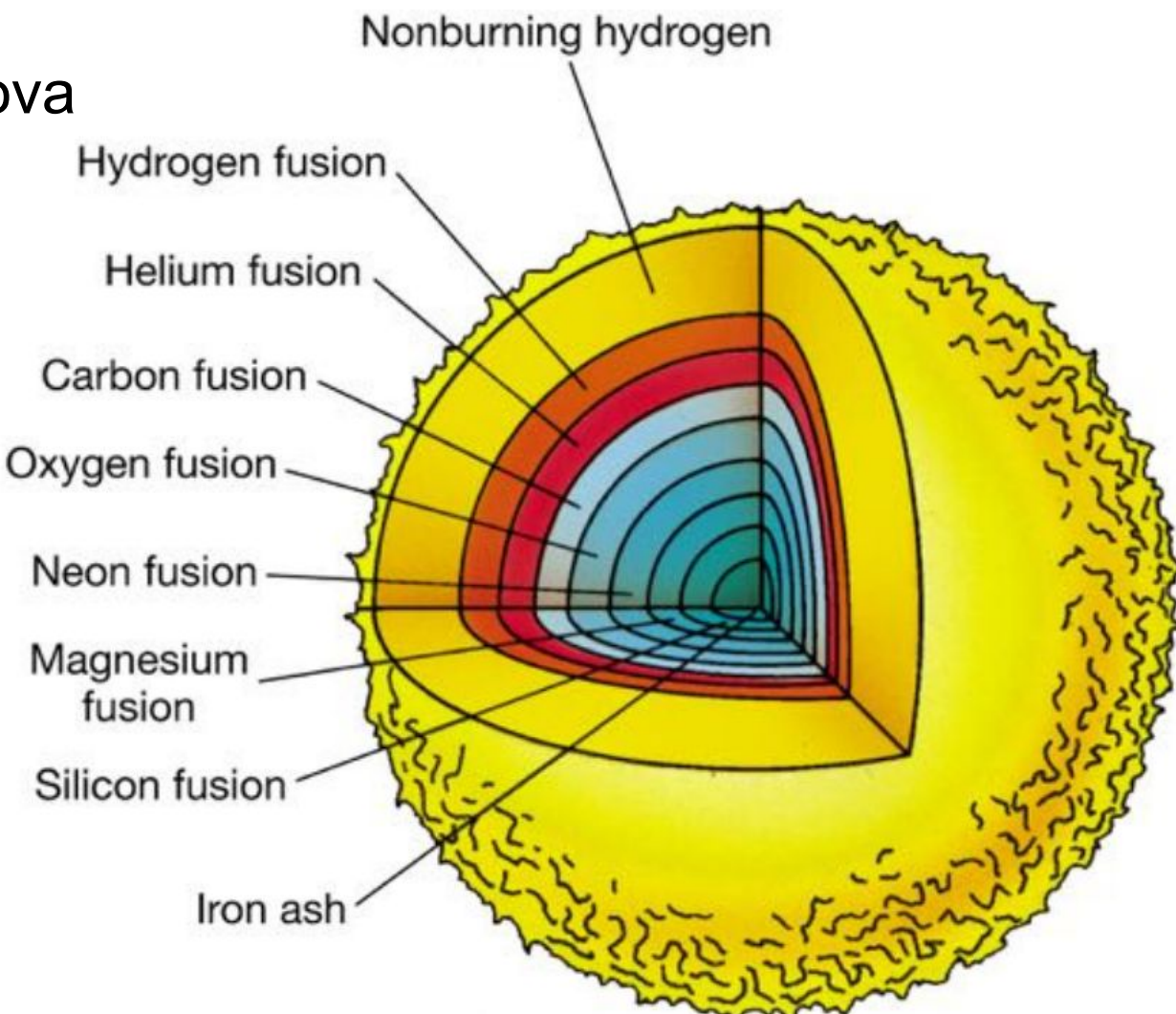
Core Collapse Supernova



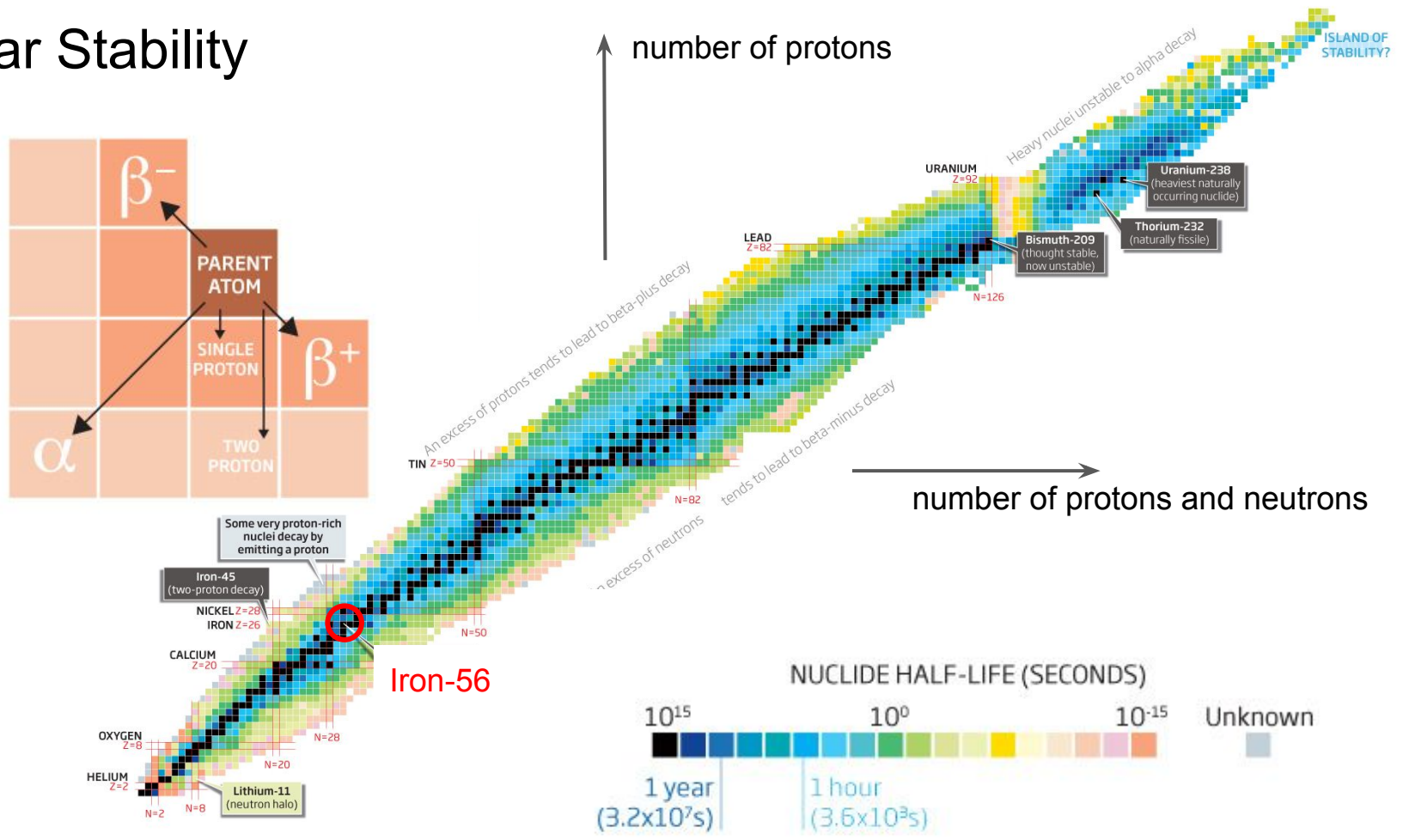
Core Collapse Supernova



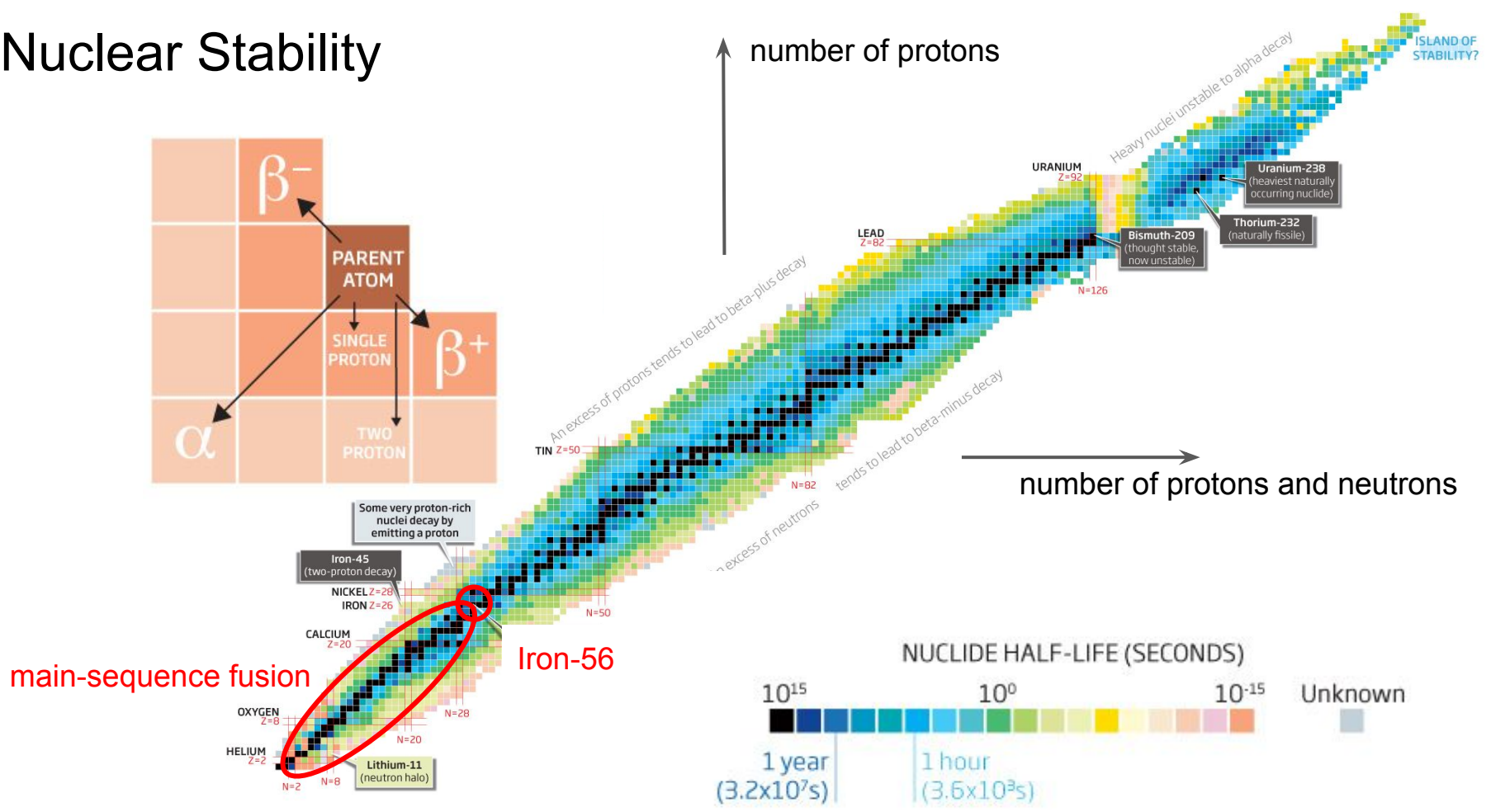
Core Collapse Supernova



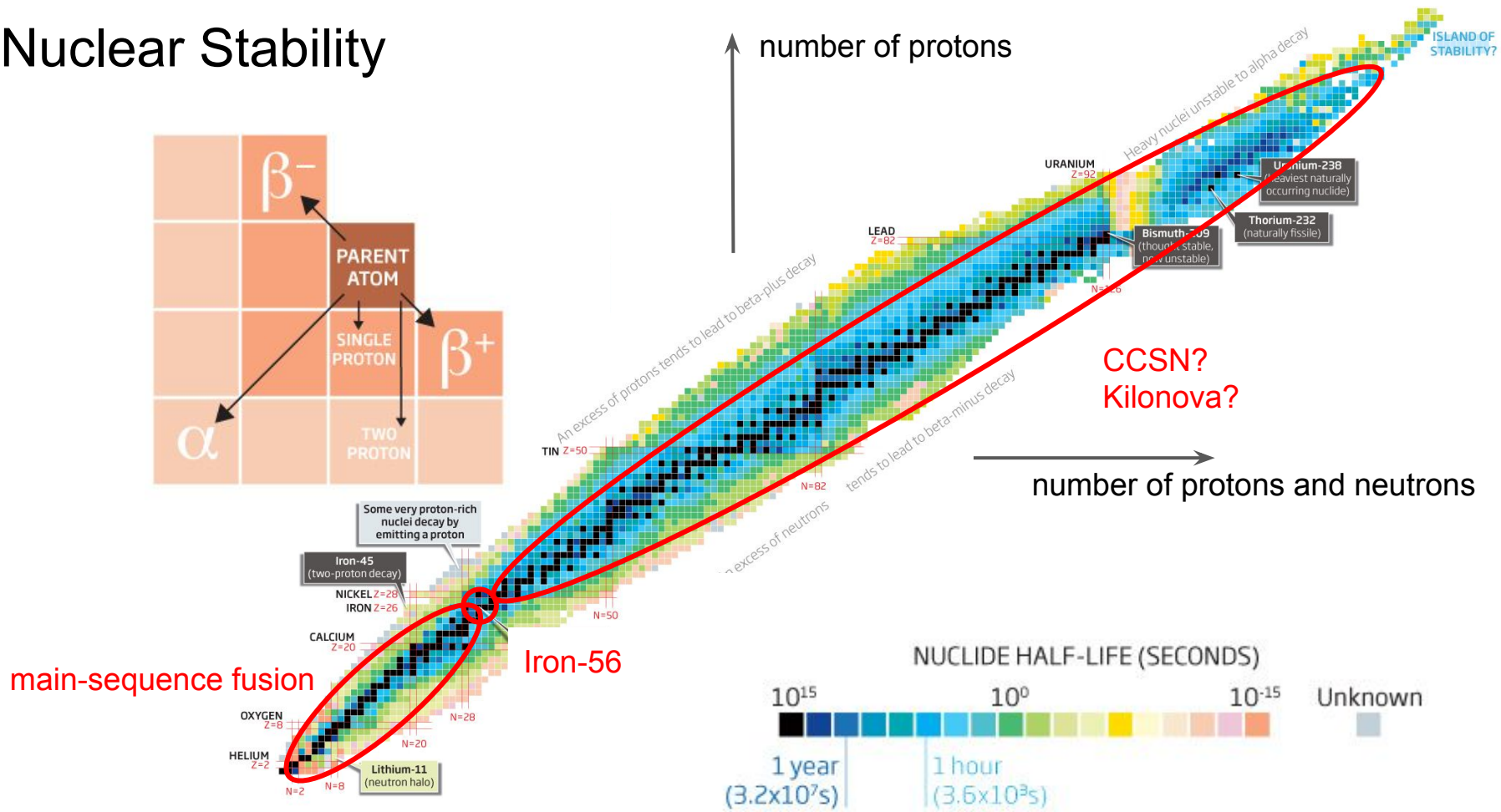
Nuclear Stability



Nuclear Stability



Nuclear Stability



CCSN?
Kilonova?

Core Collapse Supernova

particles/radiation emitted

- long GRB
- Afterglows
- Light curves
- Neutrinos

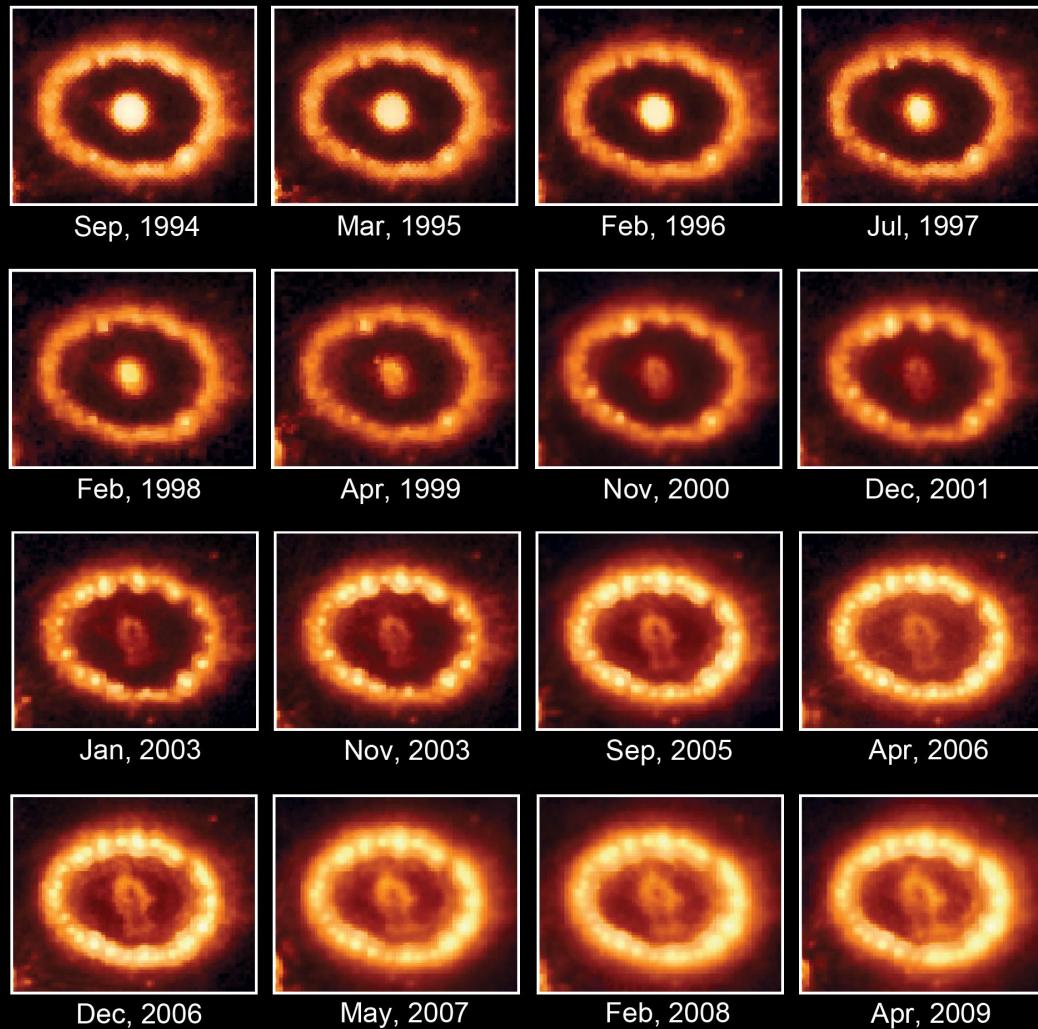
Core Collapse Supernova

particles/radiation emitted

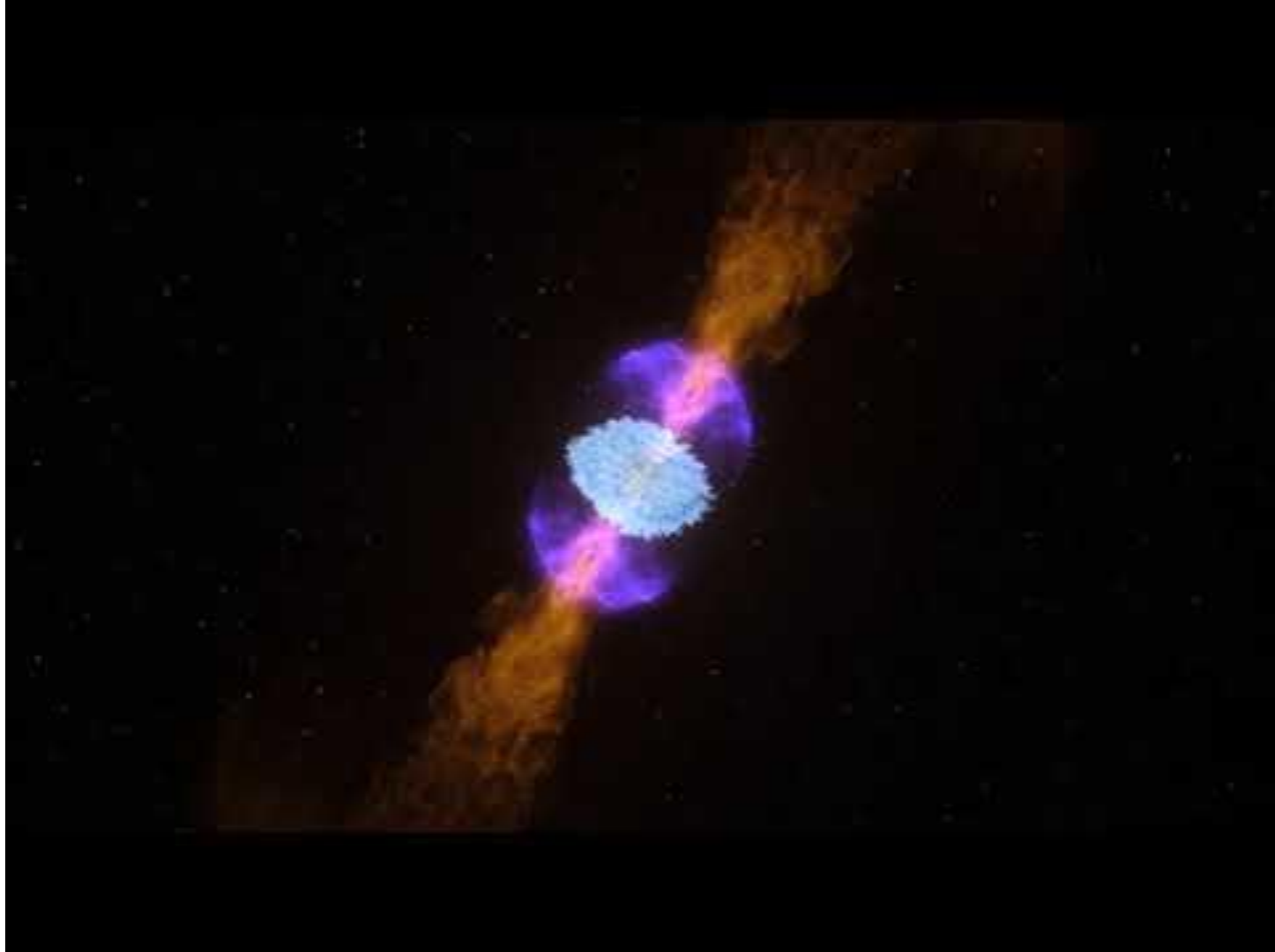
- long GRB
- Afterglows
- Light curves
- Neutrinos

what would we learn if we saw one with
multiple messengers

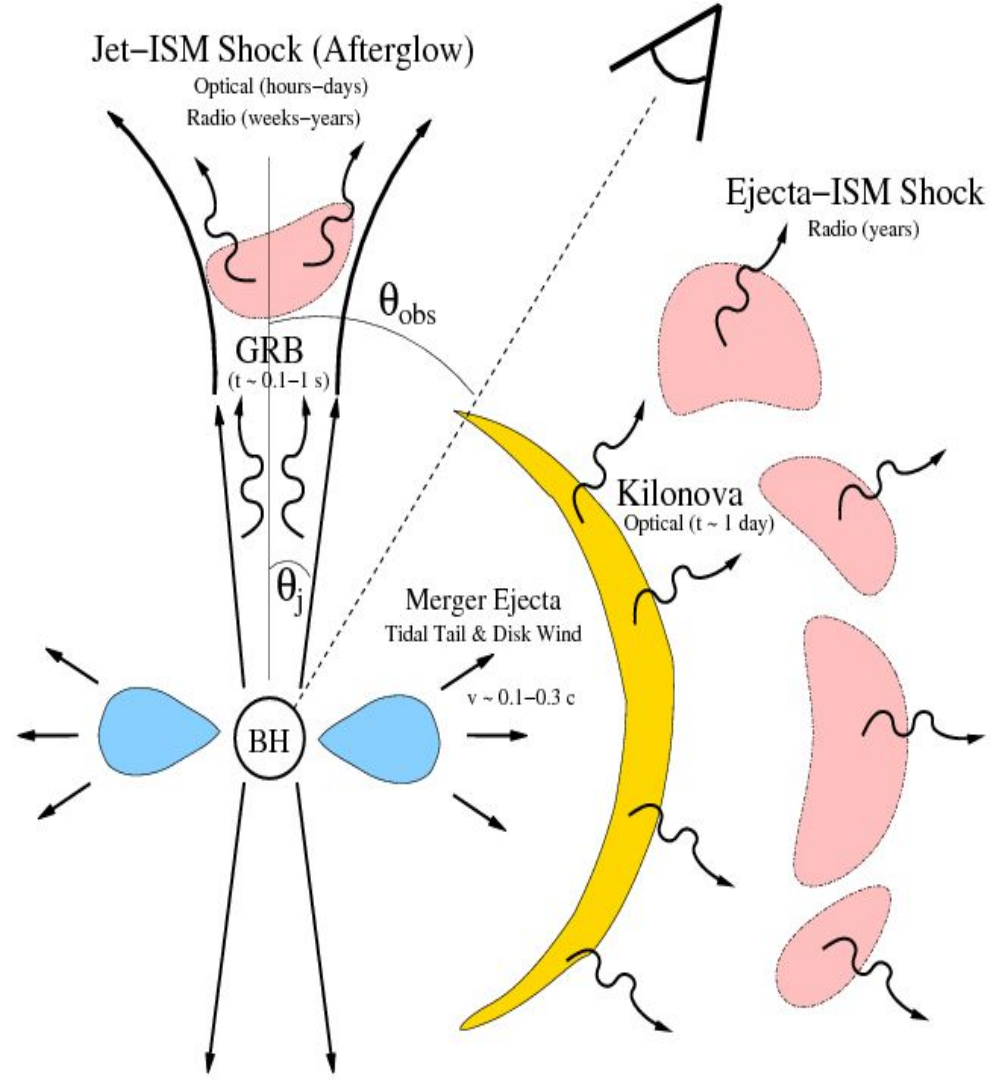
- What did we learn from SN1987a?
- What do we additionally learn with GWs?



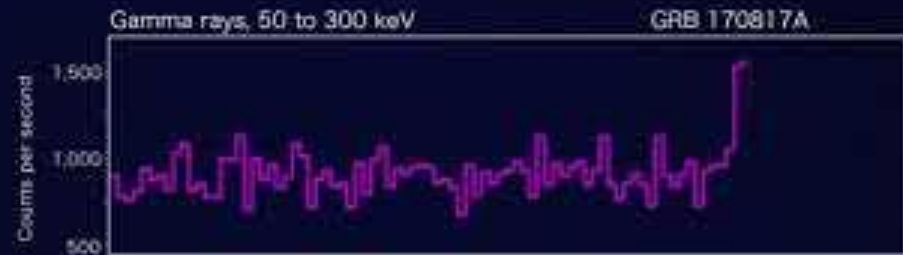
Compact Binary Coalescence



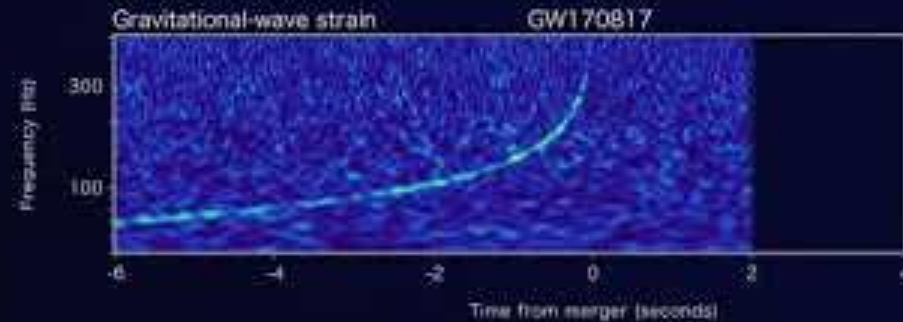
Compact Binary Coalescence



GW170817,
GRB170817a,
AT2017gfo



LIGO



GW170817, GRB170817a, AT2017gfo

GW170817
DECam observation
(0.5–1.5 days post merger)



GW170817
DECam observation
(>14 days post merger)

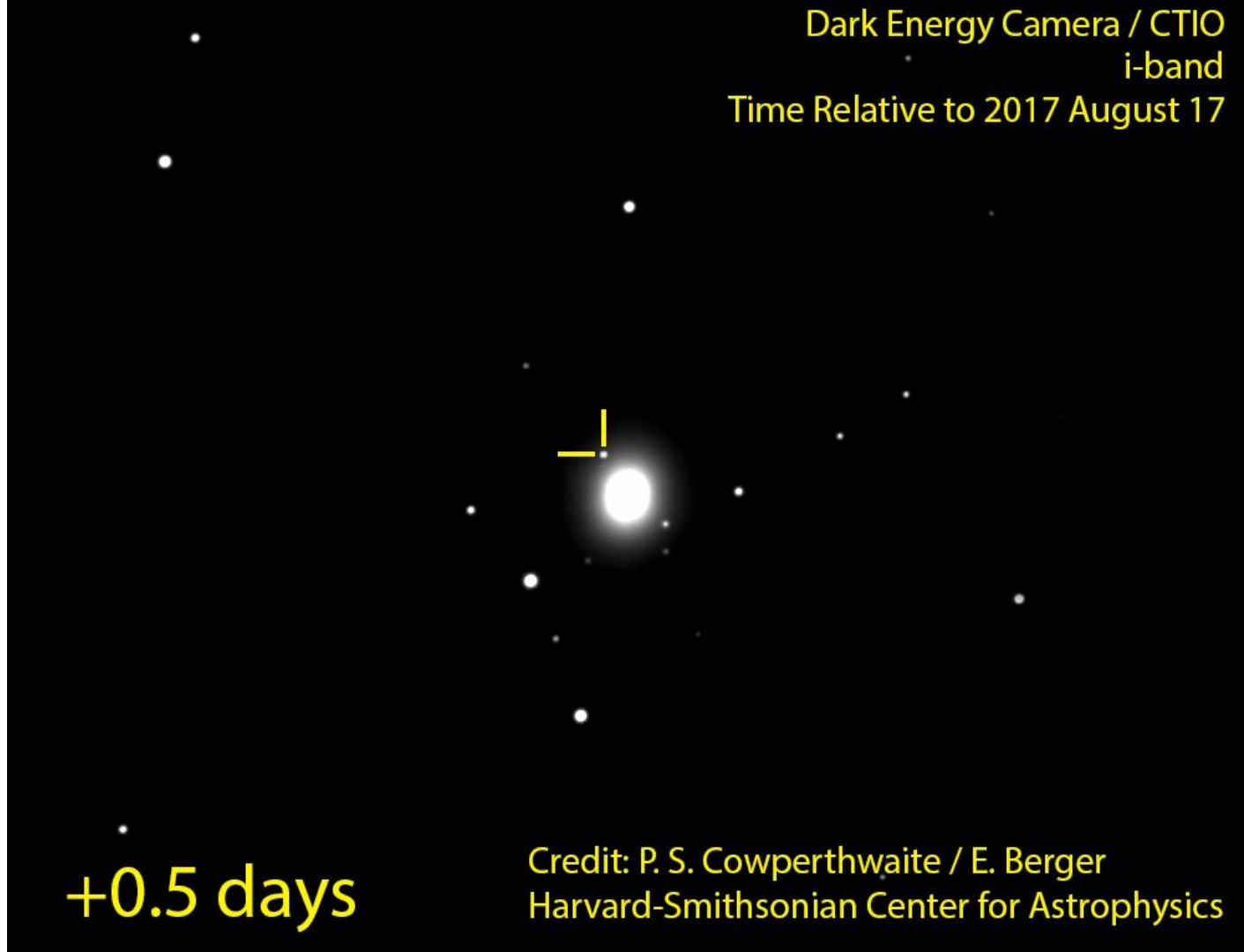


GW170817,
GRB170817a,
AT2017gfo

Dark Energy Camera / CTIO
i-band
Time Relative to 2017 August 17

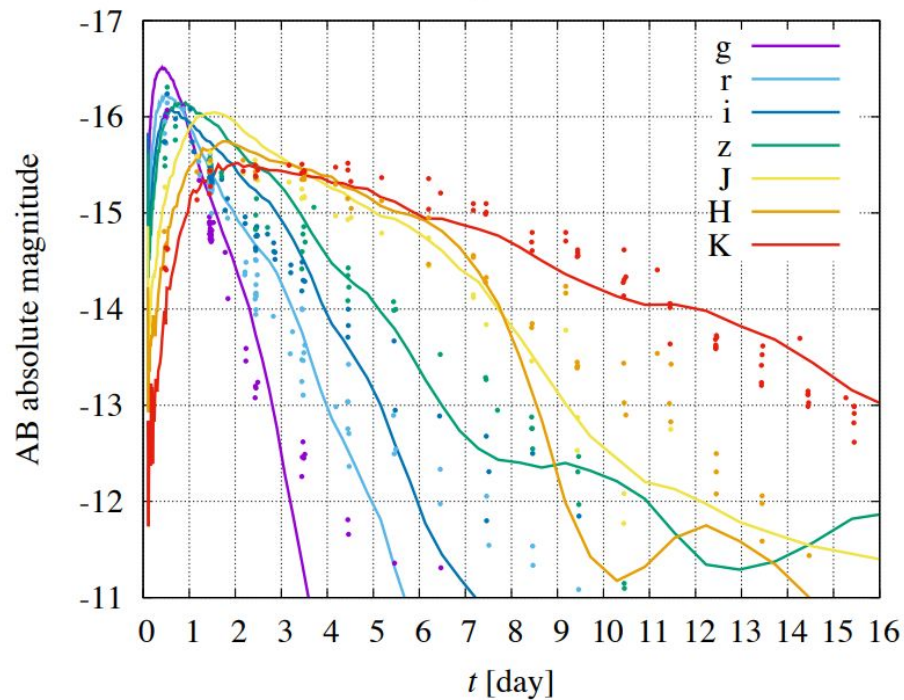
+0.5 days

Credit: P. S. Cowperthwaite / E. Berger
Harvard-Smithsonian Center for Astrophysics

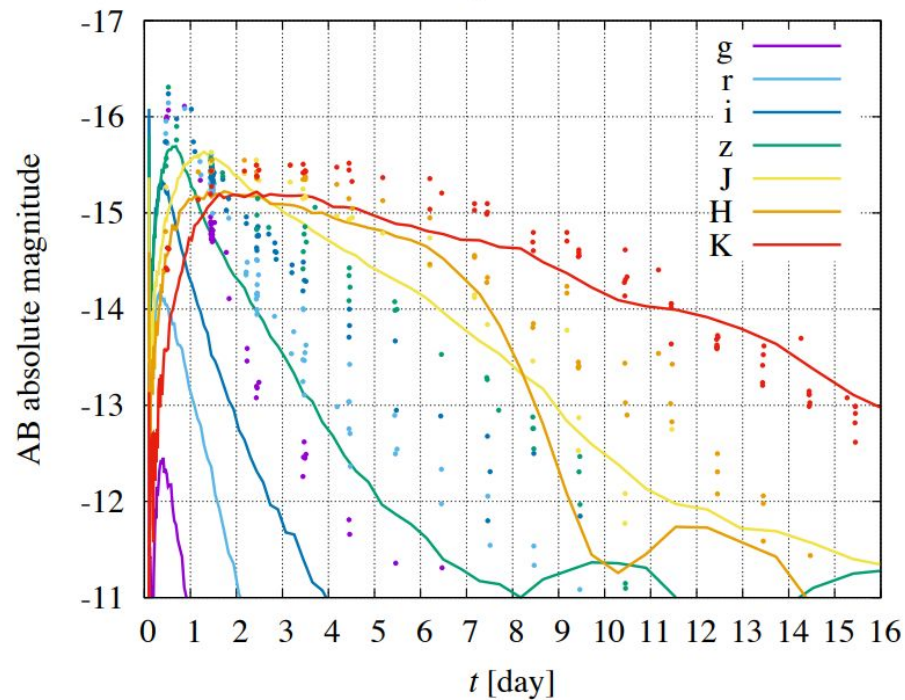


GW170817, GRB170817a, AT2017gfo

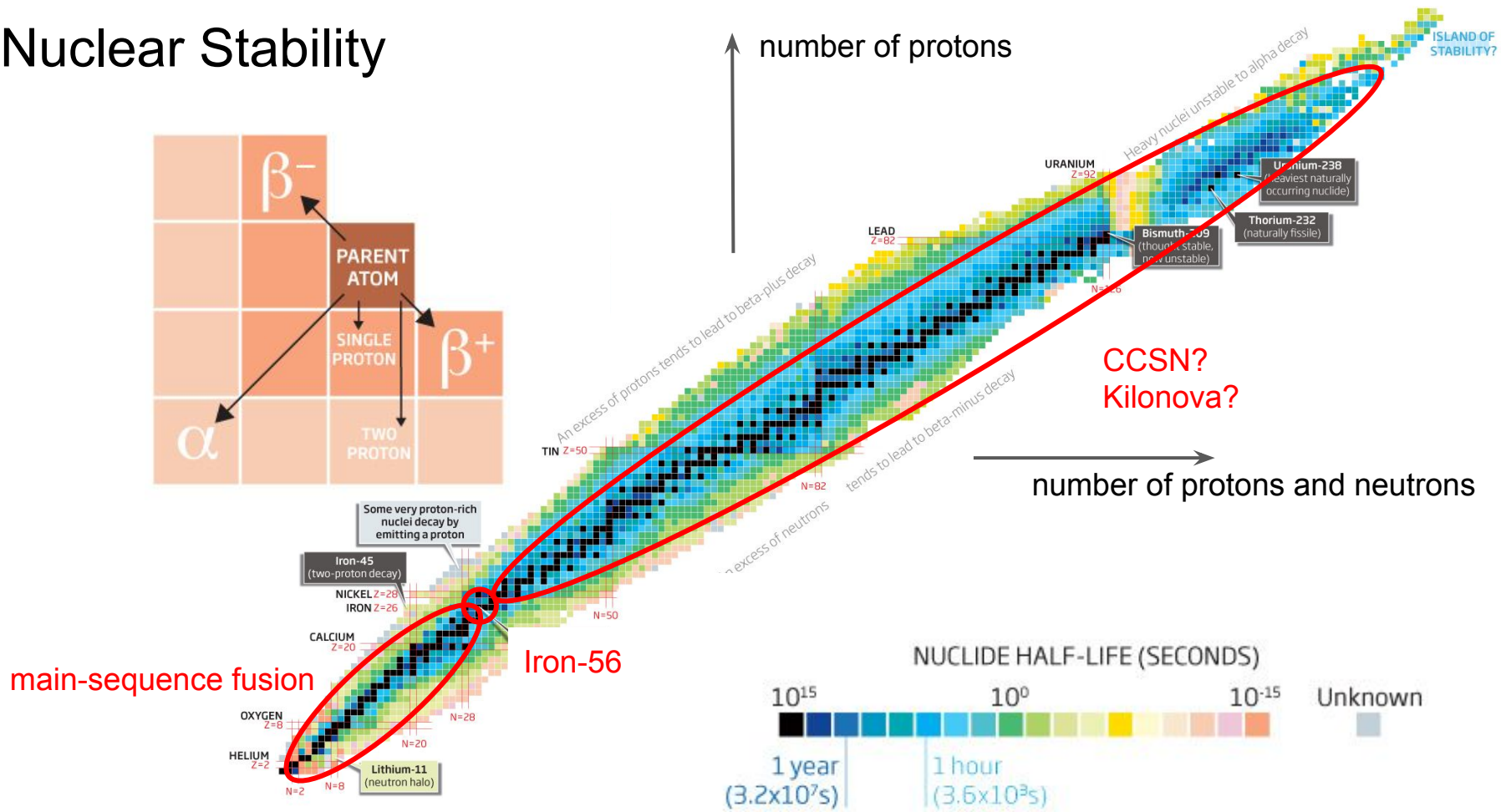
$D=40$ Mpc, $20^\circ \leq \theta < 28^\circ$



$D=40$ Mpc, $86^\circ \leq \theta < 90^\circ$

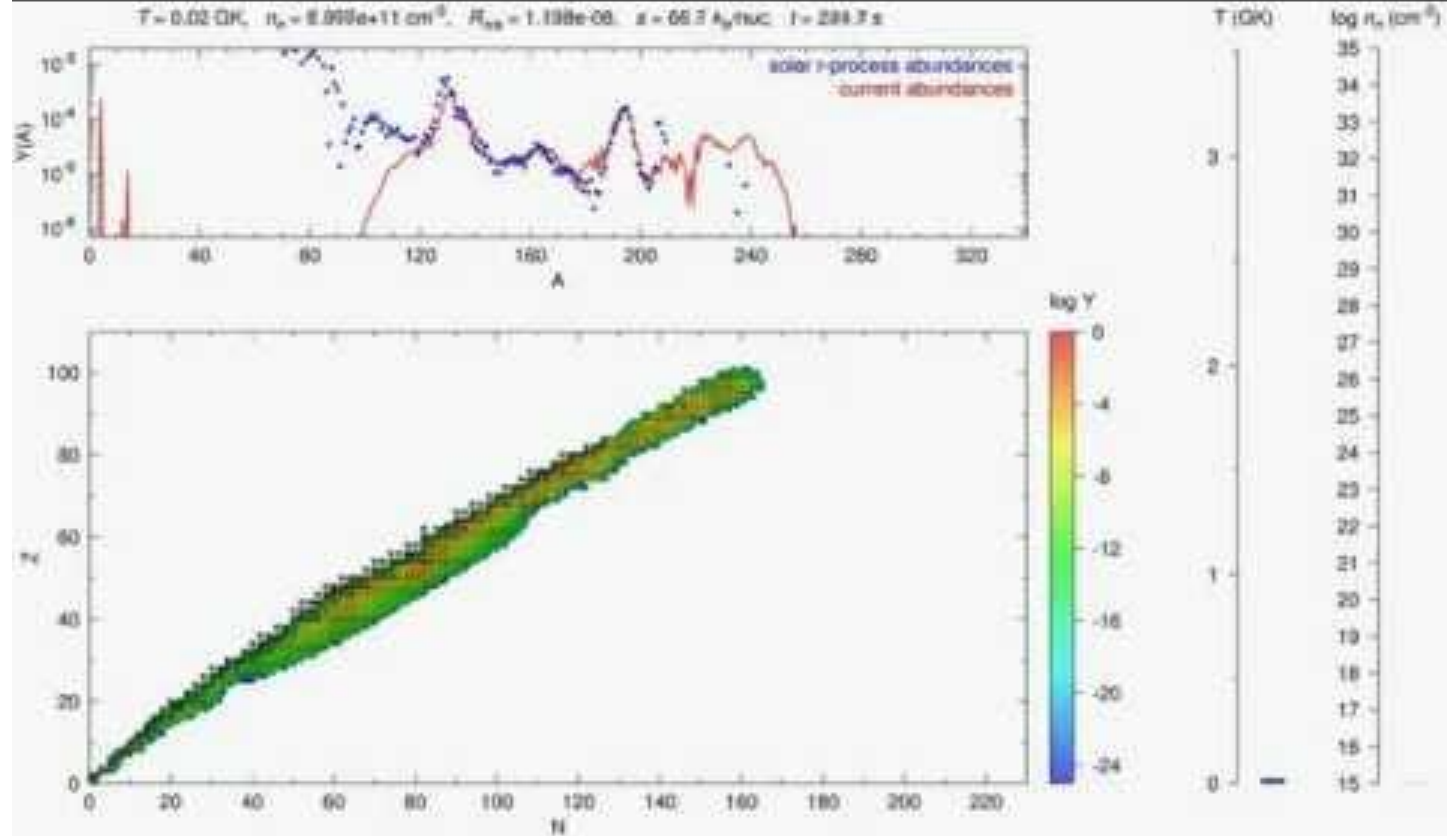


Nuclear Stability

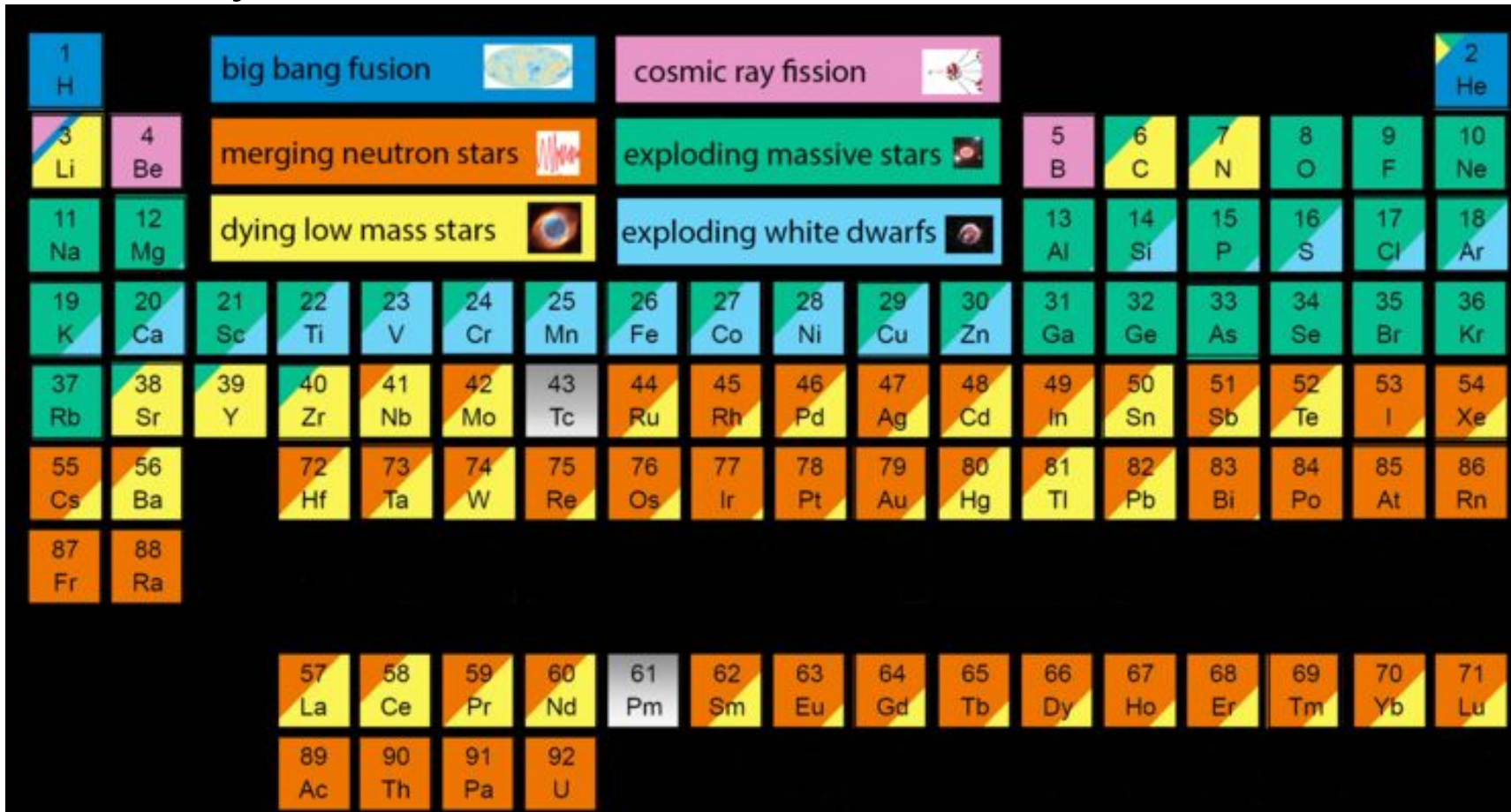


CCSN?
Kilonova?

Compact Binary Coalescence



Compact Binary Coalescence



Next time

The Physics of Neutron Stars

- What are Neutron Stars?
- What do Neutron Stars do in Compact Binary Coalescences?
- What can we learn from GW observations of Neutron Stars?

Suggested Reading

- GW170817 Fact Sheet
 - https://dcc.ligo.org/public/0146/G1702000/006/GW170817_Factsheet.pdf
- Multi-messenger Astronomy Science Summary
 - <https://www.lsc-group.phys.uwm.edu/webcommphp/science/Publication-GW170817MMA/index.php>