Astrophysics of gravitational wave sources

Lecture 1: Topics covered and implications

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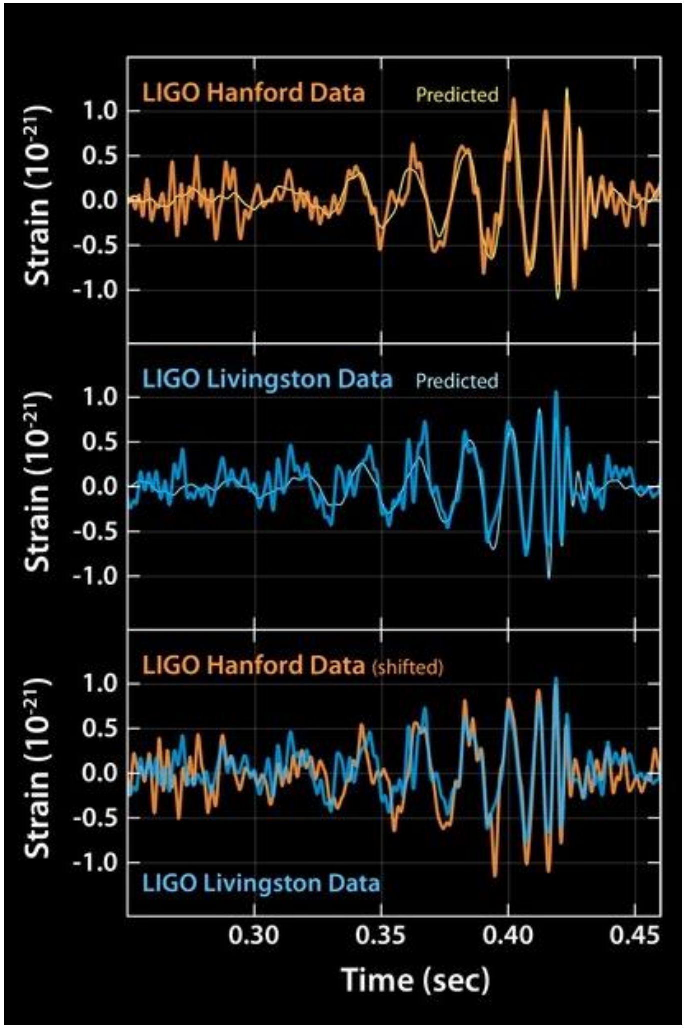
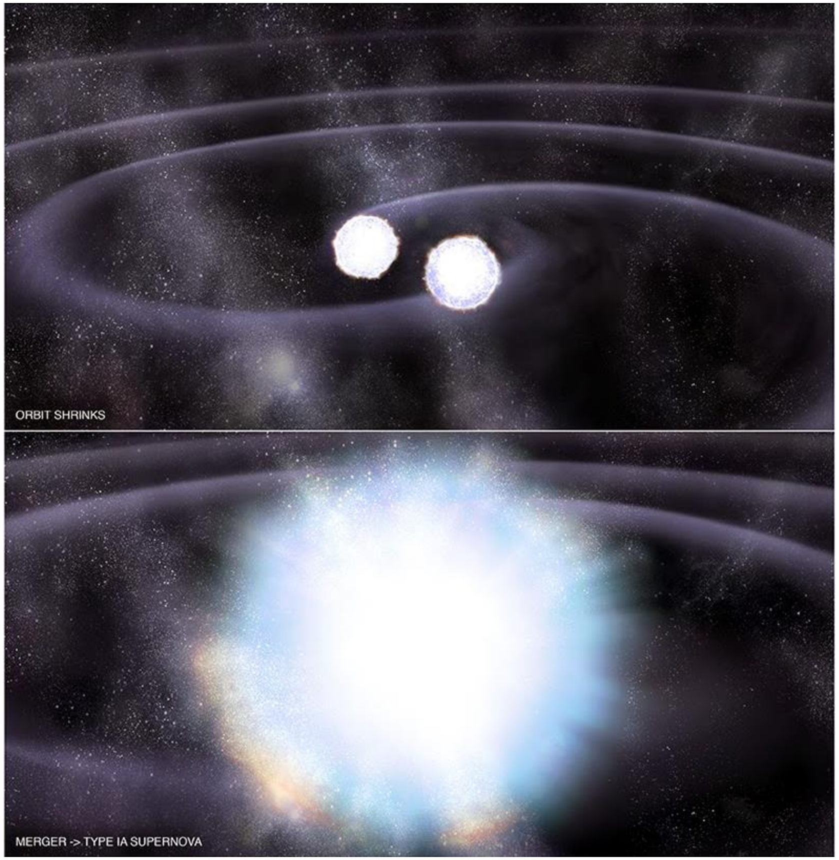
Question:

Why are all universities “excellent” in physics somewhere else?

Mergers due to gravitational wave emission

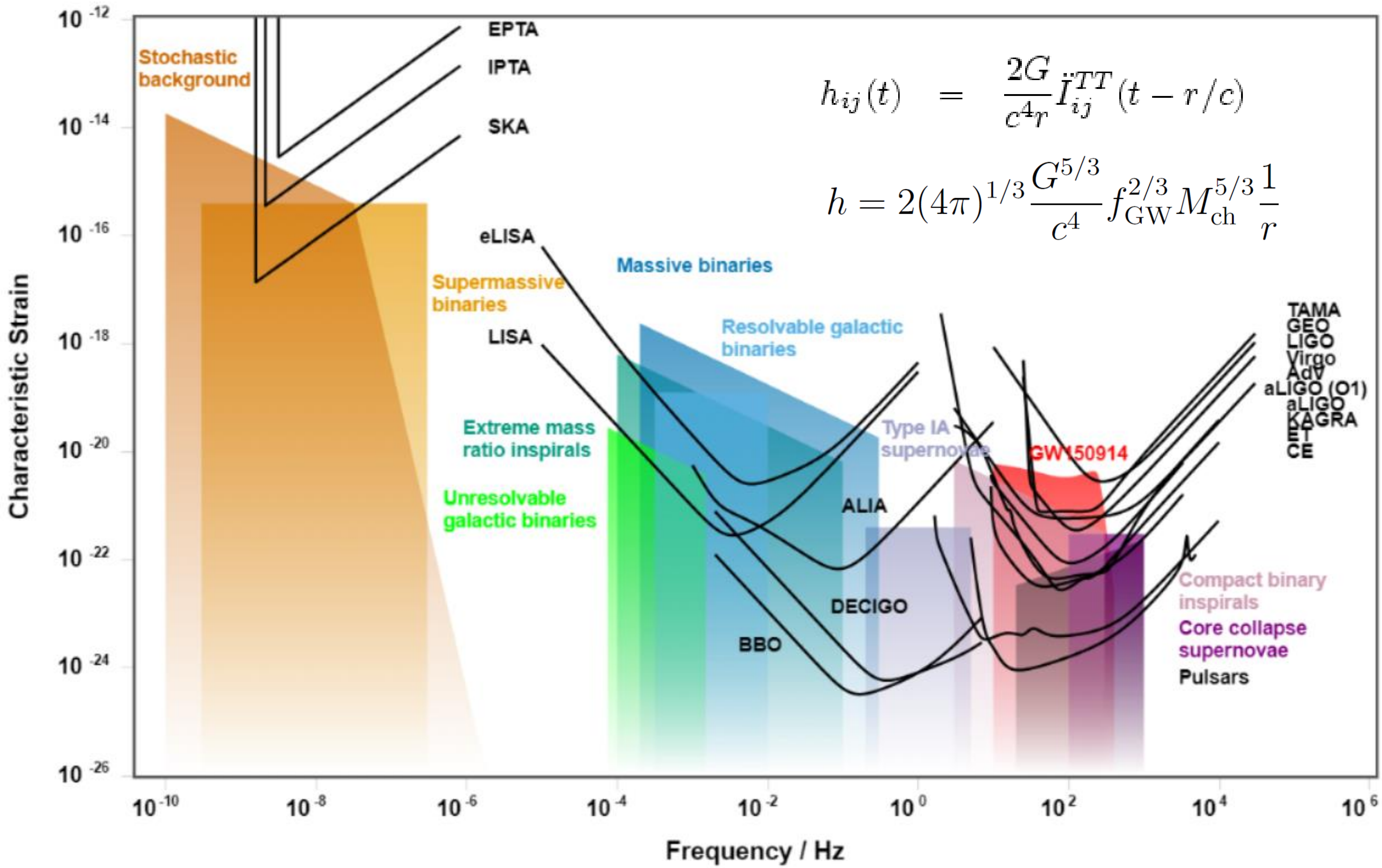


Caltech/MIT/LIGO Lab



NASA/CXC/M.Weiss

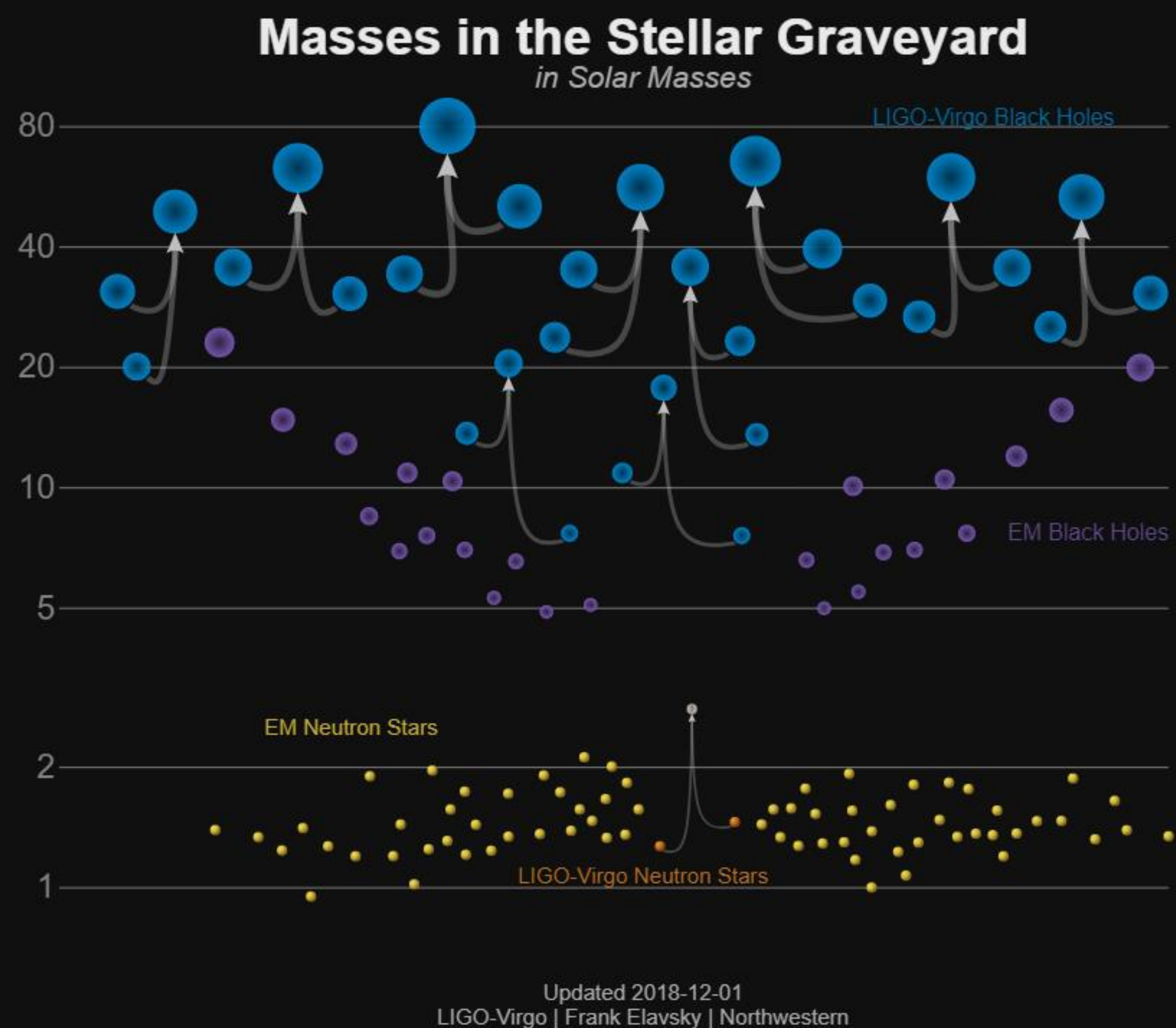
Gravitational Wave Detectors and Sources



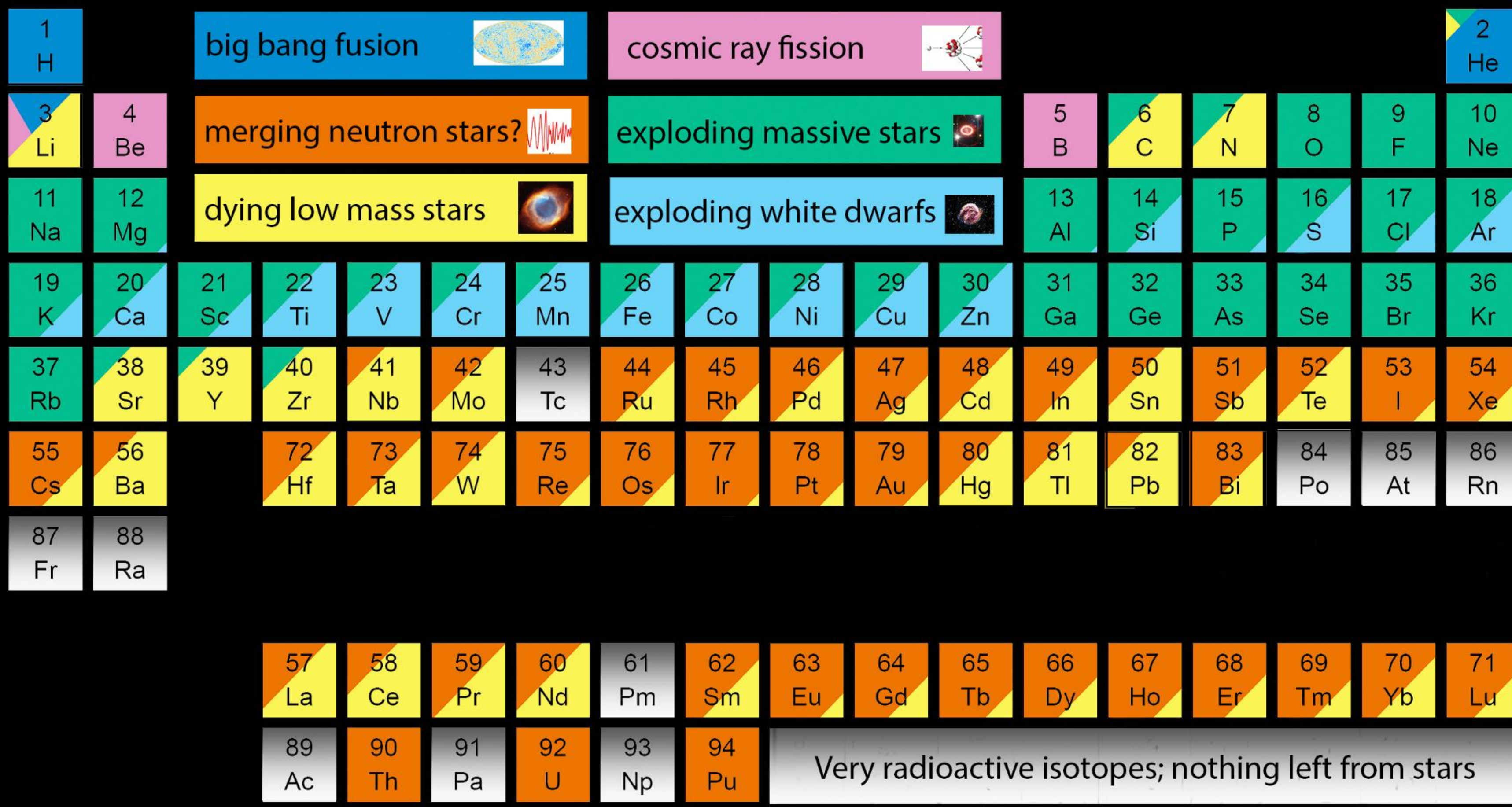
$$h_{ij}(t) = \frac{2G}{c^4 r}\ddot{I}_{ij}^{TT}(t - r/c)$$

$$h = 2(4\pi)^{1/3}\frac{G^{5/3}}{c^4}f_{\rm GW}^{2/3}M_{\rm ch}^{5/3}\frac{1}{r}$$

gwplotter.com


Masses in the Stellar Graveyard
in Solar Masses
80
40
20
10
5
2
1
LIGO-Virgo Black Holes
EM Black Holes
EM Neutron Stars
LIGO-Virgo Neutron Stars
Updated 2018-12-01
LIGO-Virgo | Frank Elavsky | Northwestern

The Origin of the Solar System Elements

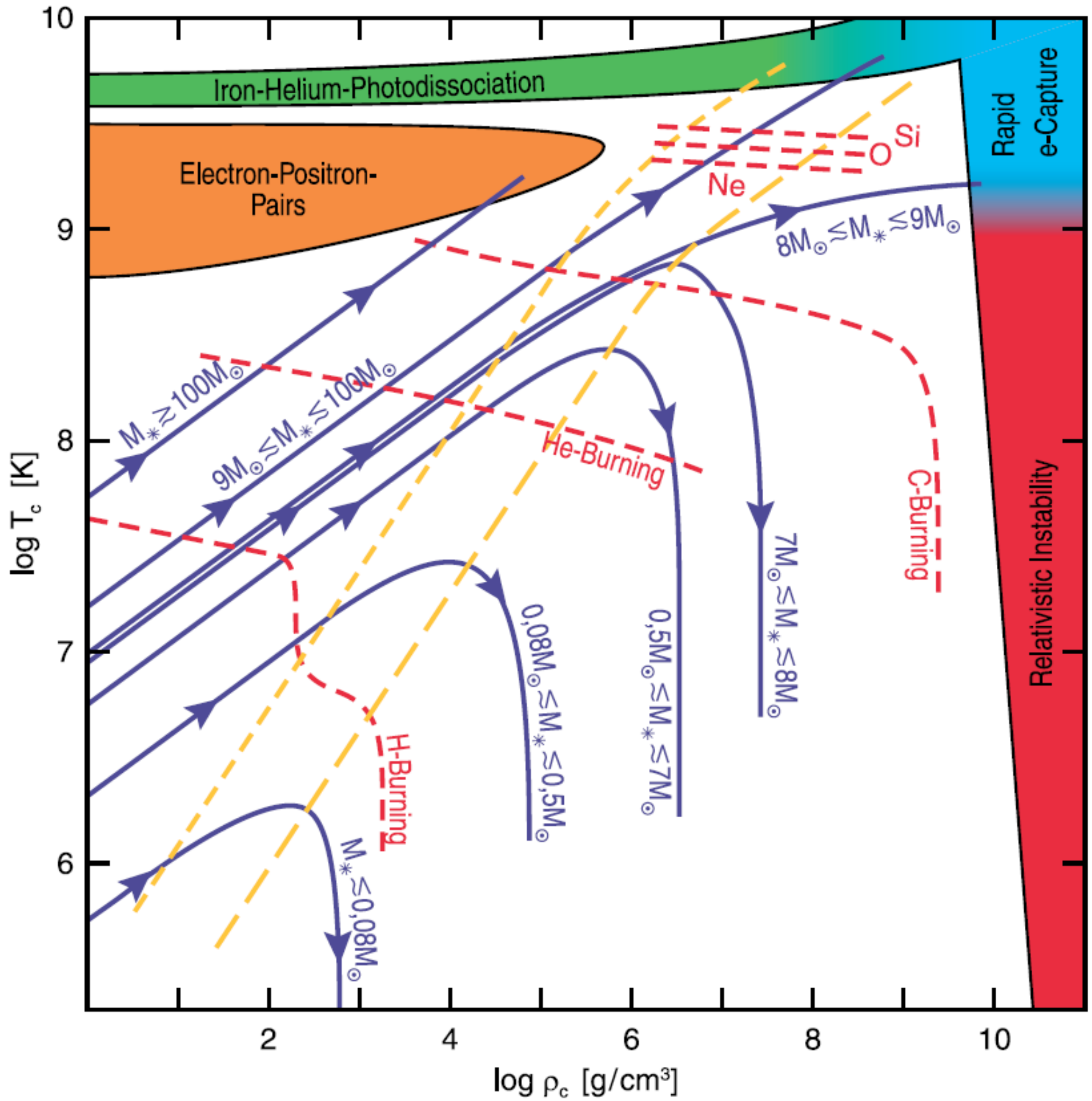


Graphic created by Jennifer Johnson
http://www.astronomy.ohio-state.edu/~jaj/nucleo/

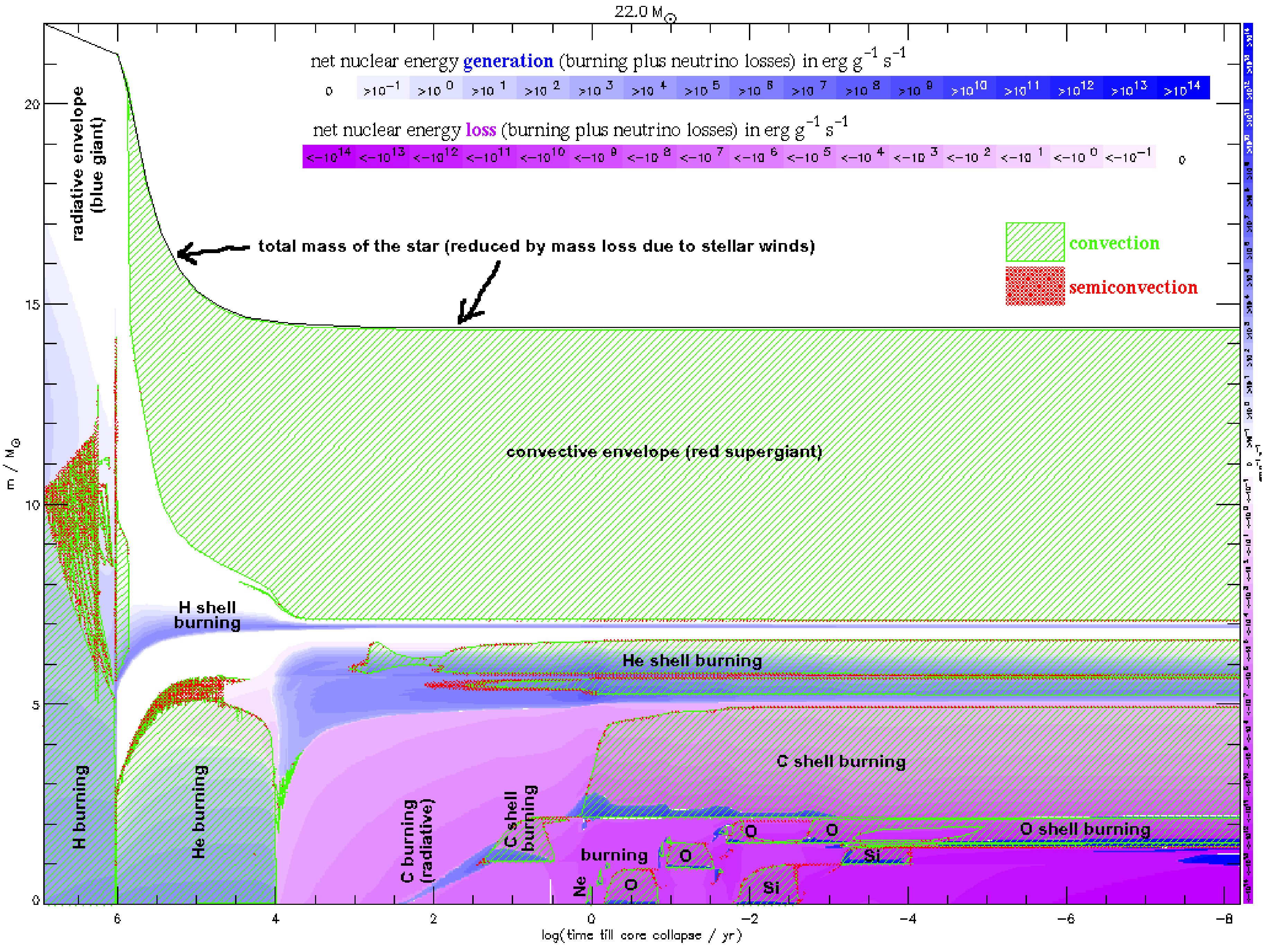
Astronomical Image Credits:
ESA/NASA/AASNova

Single star evolution

Central temperature and pressure



Janka (2012)

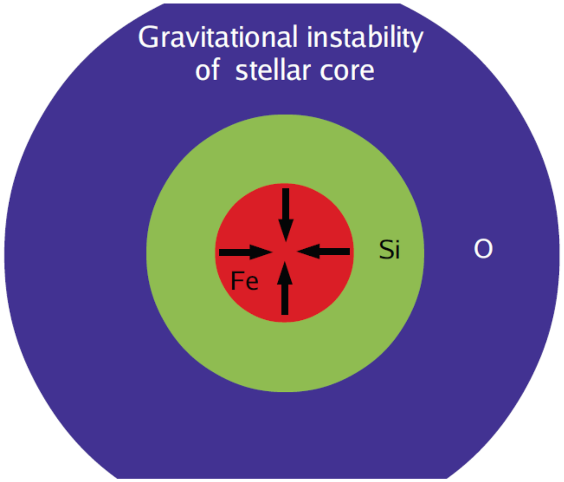


A. Heger website 2sn.org

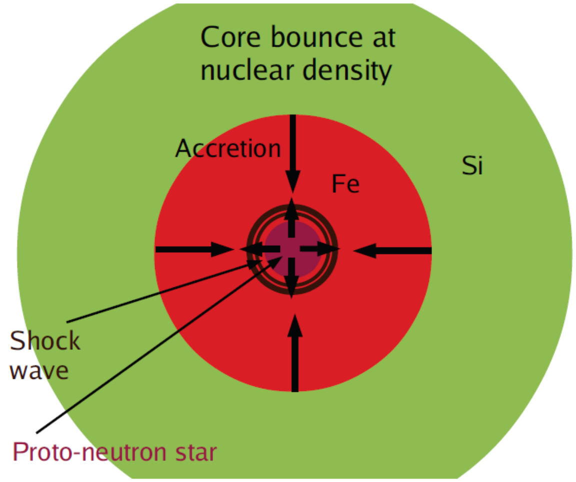
1 erg = 10^{-7} J

Massive star death

1 $L_\odot$ = 3.9 × 10^{33} ergs/s

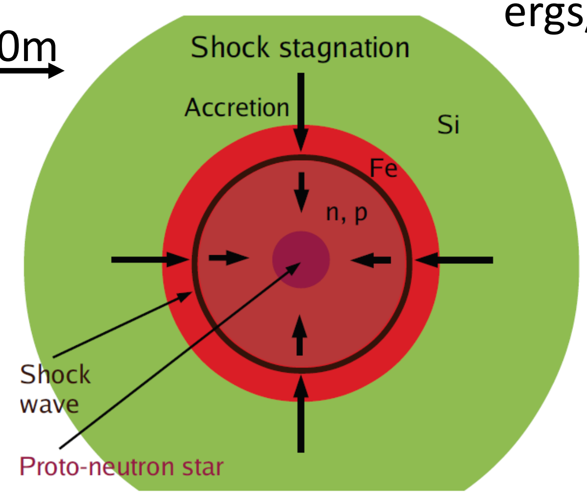


$M_{initial}$ > 8 $M_\odot$
Collapse from WD size ~0.3s



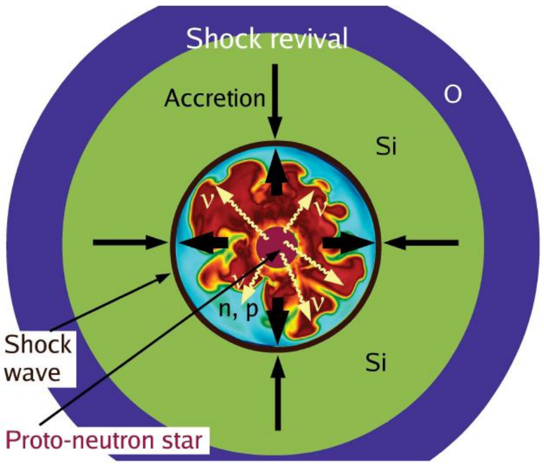
Proto-neutron star ~60 km
Binding energy ~ 3 × 10^{53} ergs

<10m s

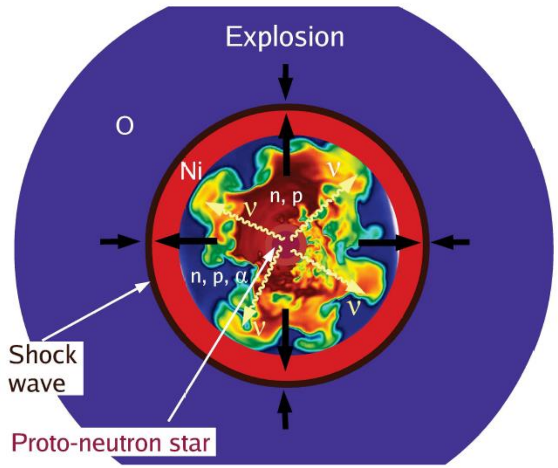


Stalled shock at 100-200 km
Neutrino cooling ~ 10^{52} ergs/s
Duration up to ~1 s

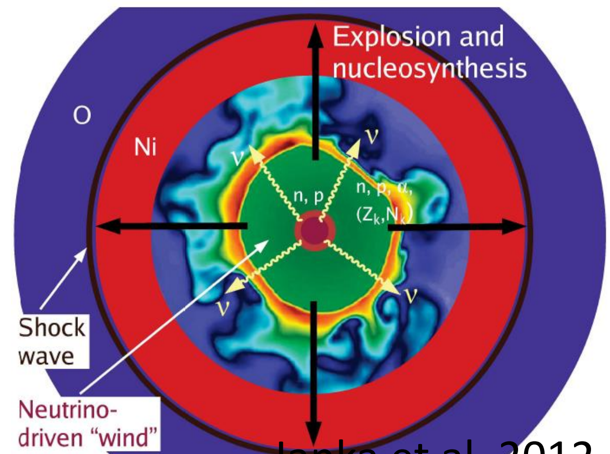
Reason not fully understood



All NS binding energy released before 10-100s



Explosion energy ~10^{51} ergs
10^{-3} – 10^{-1} $M_\odot$ of Nickel-56
Shock at surface in ~hours



Janka et al. 2012

Binary star evolution

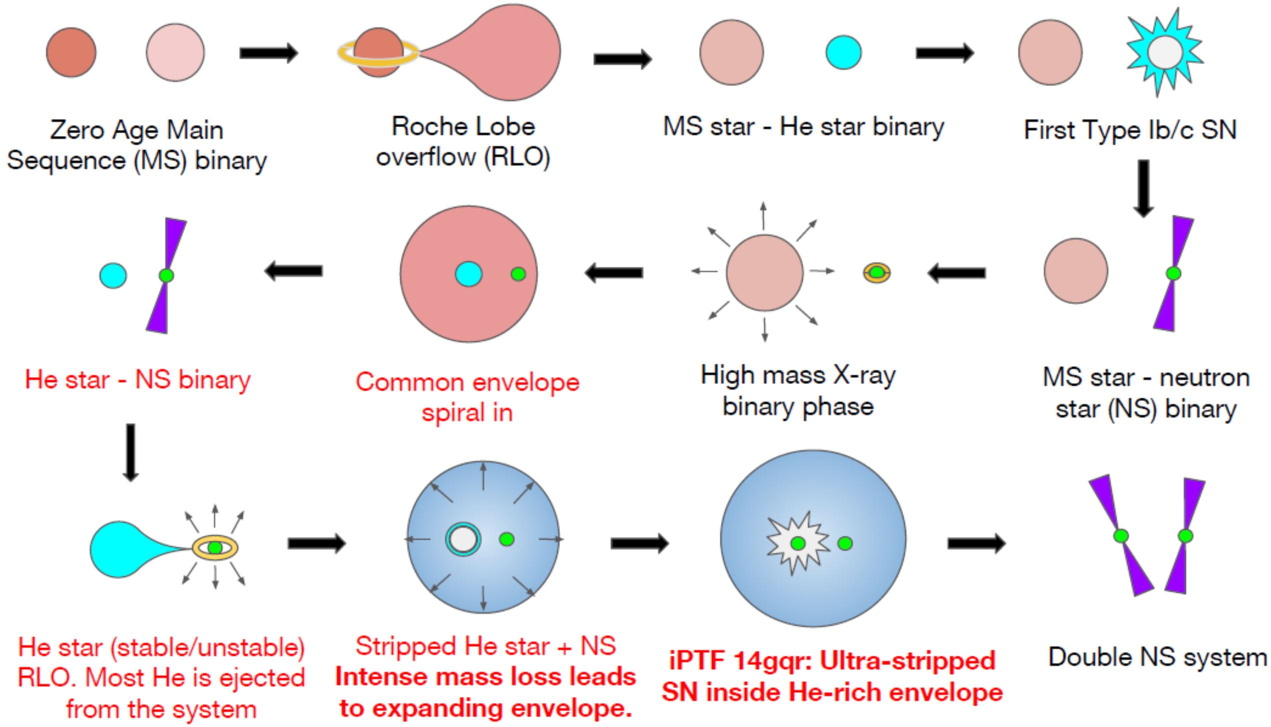
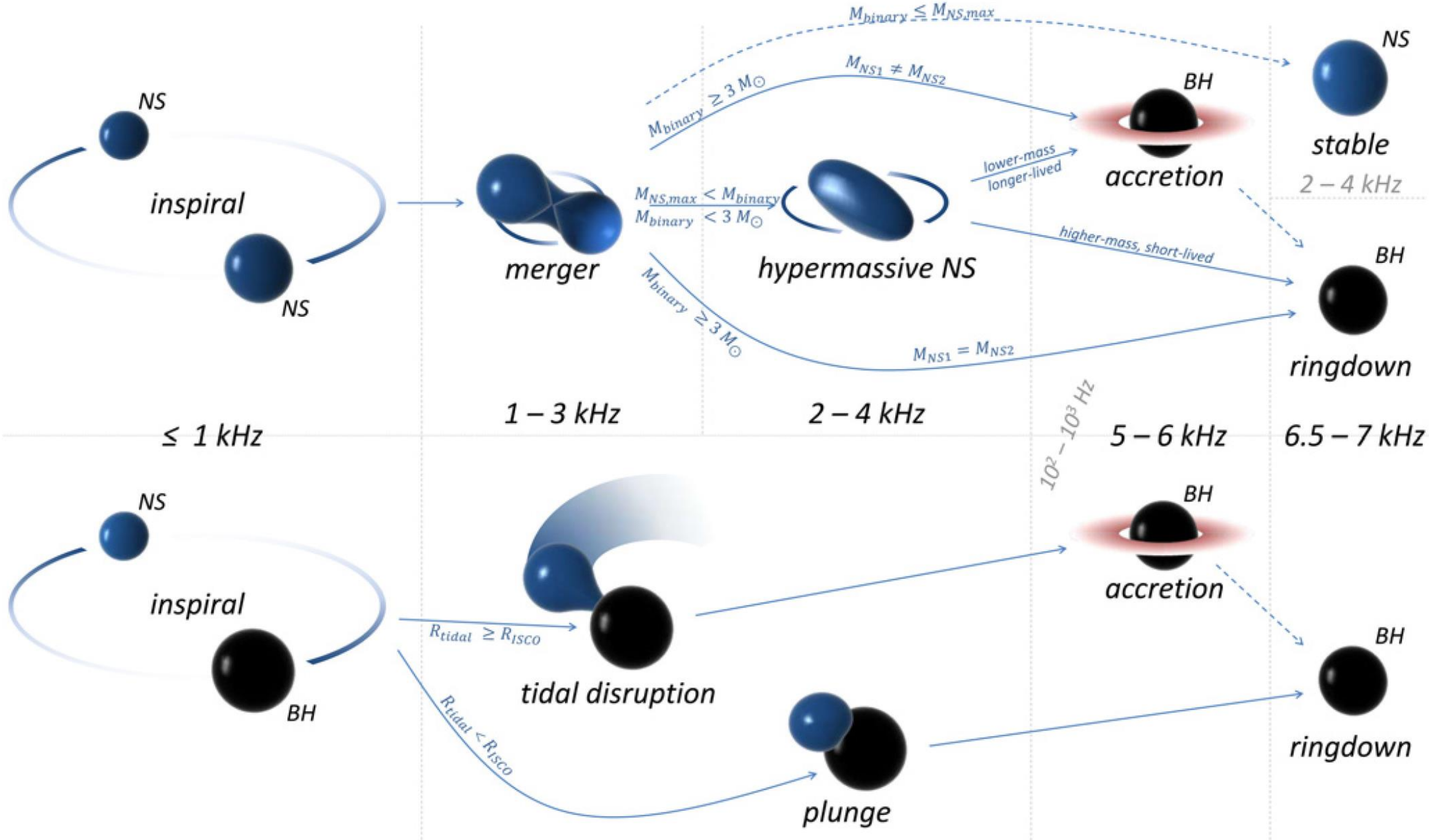


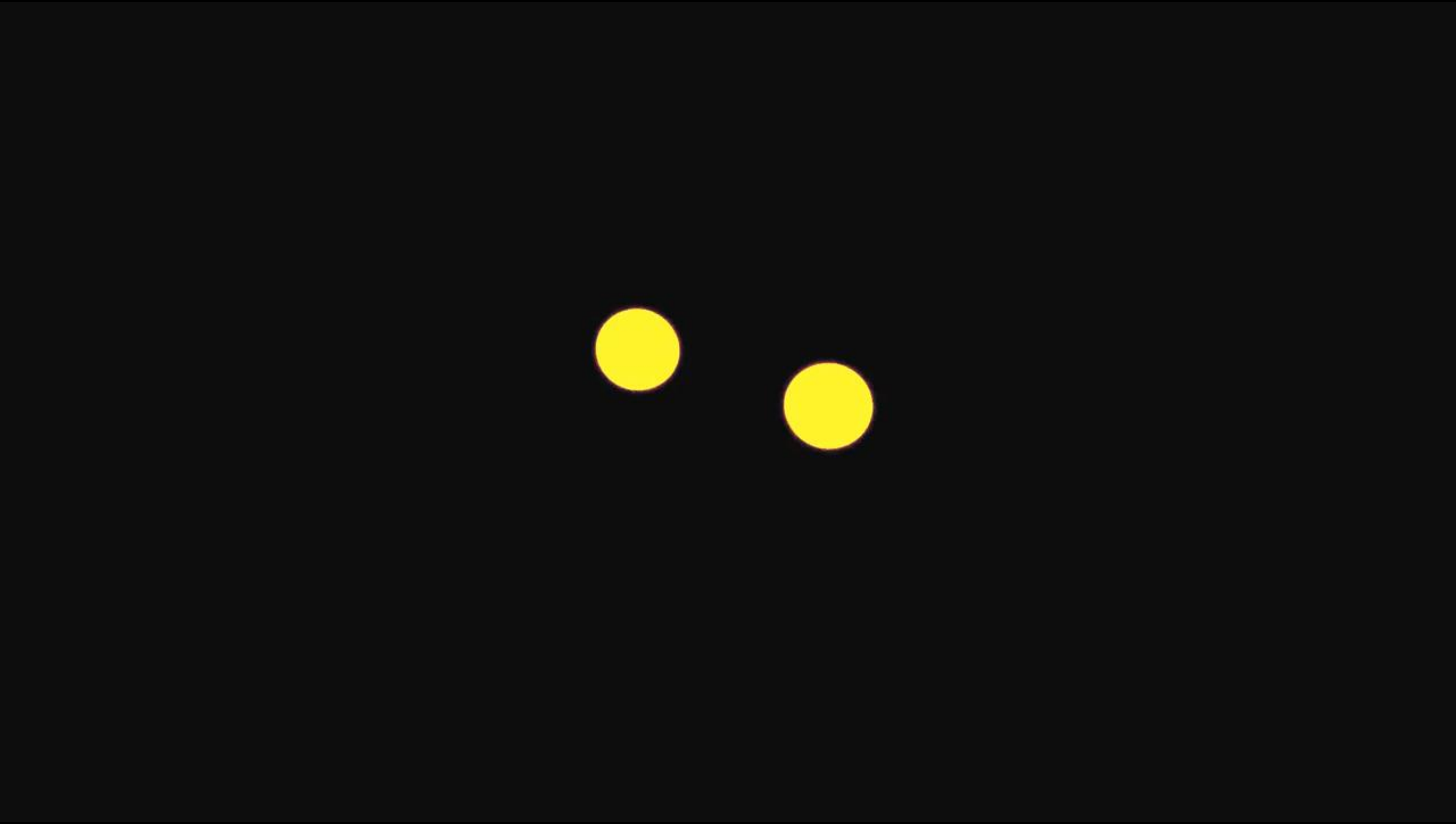
Figure 6: **Stellar evolutionary sequence leading from a binary system of massive stars (starting from the top left) to a NS-NS system, adapted from (*9*).** NS-BH systems are expected to arise from binaries where the first formed compact object is a BH. NS-WD systems follow a similar evolutionary sequence starting from the HMXB stage (where the NS is replaced by the WD), but require additional mass transfer in the earlier stages (*52*). The material composition of the stars is indicated by their colors – red indicates H-rich material, cyan / blue indicate He-rich material, grey indicates CO-rich material and green indicates degenerate matter (in NS). The specific phase of the evolution is indicated by the text next to the systems, with black text indicating phases that have been observed previously, while red text indicates phases that have not been previously observed, and bold red text phases we observed in this work.

De et al. (2018)

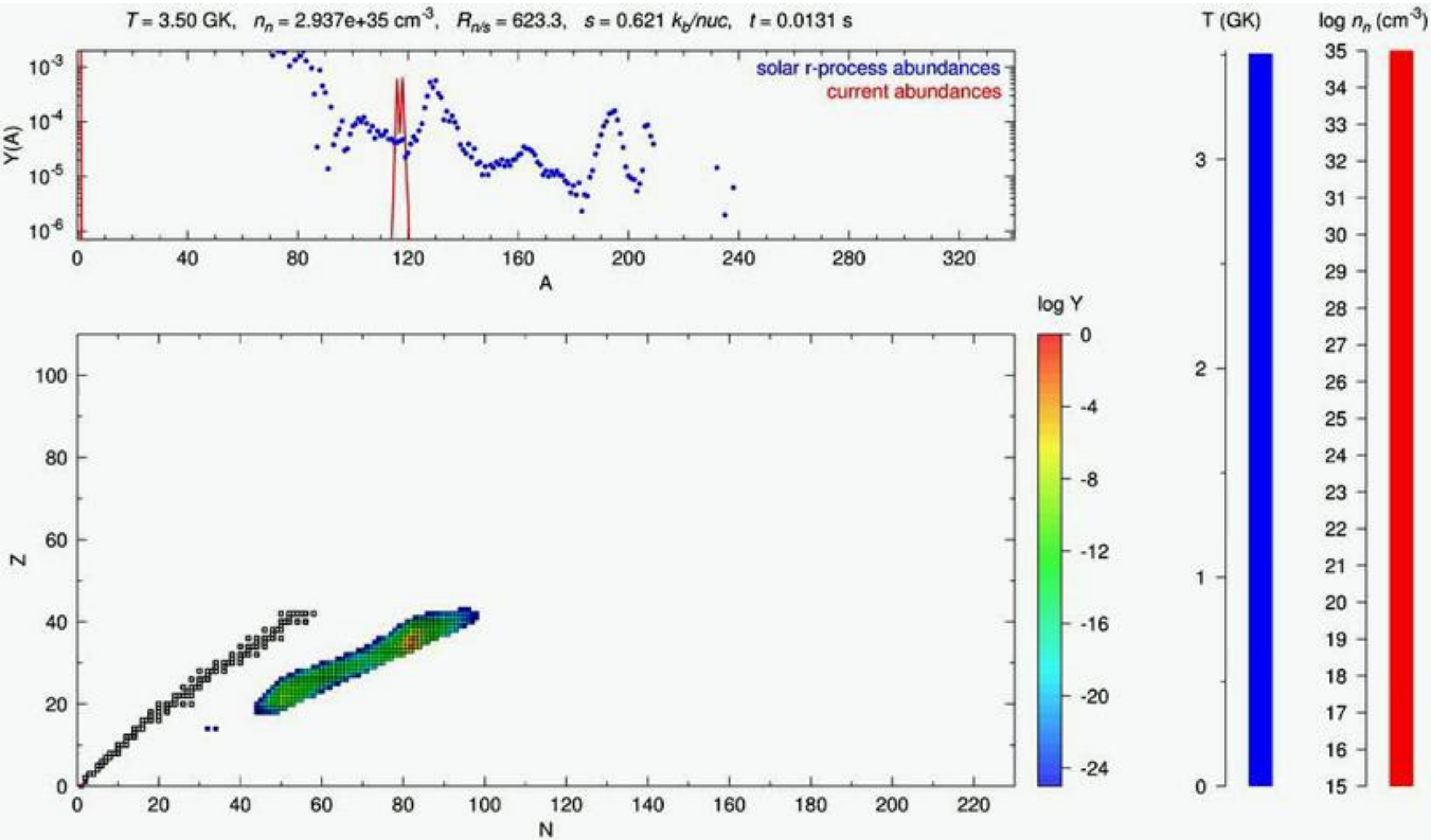


Bartos et al. (2013

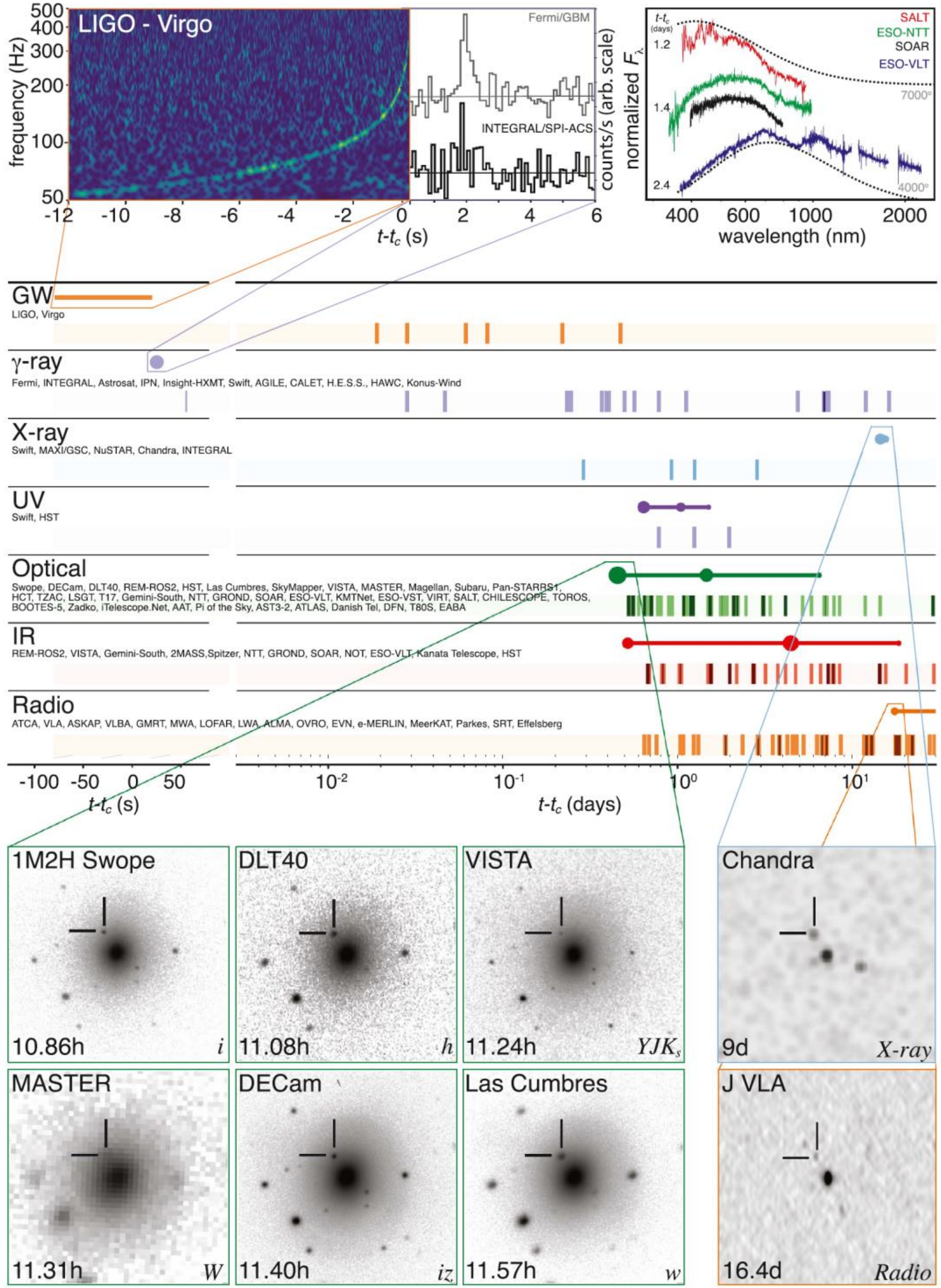
Binary neutron star mergers



Radice et al.



T = 3.50 GK, n_n = 2.937e+35 cm^-3, R_n/s = 623.3, s = 0.621 k_b/nuc, t = 0.0131 s
solar r-process abundances
current abundances
Y(A)
A
Z
N
log Y
T (GK)
log n_n (cm^-3)


LIGO - Virgo
frequency (Hz)
t-t_c (s)
Fermi/GBM
INTEGRAL/SPI-ACS
counts/s (arb. scale)
normalized F_λ
SALT
ESO-NTT
SOAR
ESO-VLT
wavelength (nm)
GW
LIGO, Virgo
γ-ray
Fermi, INTEGRAL, Astrosat, IPN, Insight-HXMT, Swift, AGILE, CALET, H.E.S.S., HAWC, Konus-Wind
X-ray
Swift, MAXI/GSC, NuSTAR, Chandra, INTEGRAL
UV
Swift, HST
Optical
Swope, DECam, DLT40, REM-ROS2, HST, Las Cumbres, SkyMapper, VISTA, MASTER, Magellan, Subaru, Pan-STARRS1, HCT, TZAC, LSGT, T17, Gemini-South, NTT, GROND, SOAR, ESO-VLT, KMTNet, ESO-VST, VIRT, SALT, CHILESCOPE, TOROS, BOOTES-5, Zadko, iTelescope.Net, AAT, Pi of the Sky, AST3-2, ATLAS, Danish Tel, DFN, T80S, EABA
IR
REM-ROS2, VISTA, Gemini-South, 2MASS,Spitzer, NTT, GROND, SOAR, NOT, ESO-VLT, Kanata Telescope, HST
Radio
ATCA, VLA, ASKAP, VLBA, GMRT, MWA, LOFAR, LWA, ALMA, OVRO, EVN, e-MERLIN, MeerKAT, Parkes, SRT, Effelsberg
t-t_c (s)
t-t_c (days)
1M2H Swope 10.86h i
DLT40 11.08h h
VISTA 11.24h YJK_s
Chandra 9d X-ray
MASTER 11.31h W
DECam 11.40h iz
Las Cumbres 11.57h w
J VLA 16.4d Radio

Question:

Why are all universities “excellent” in physics somewhere else?

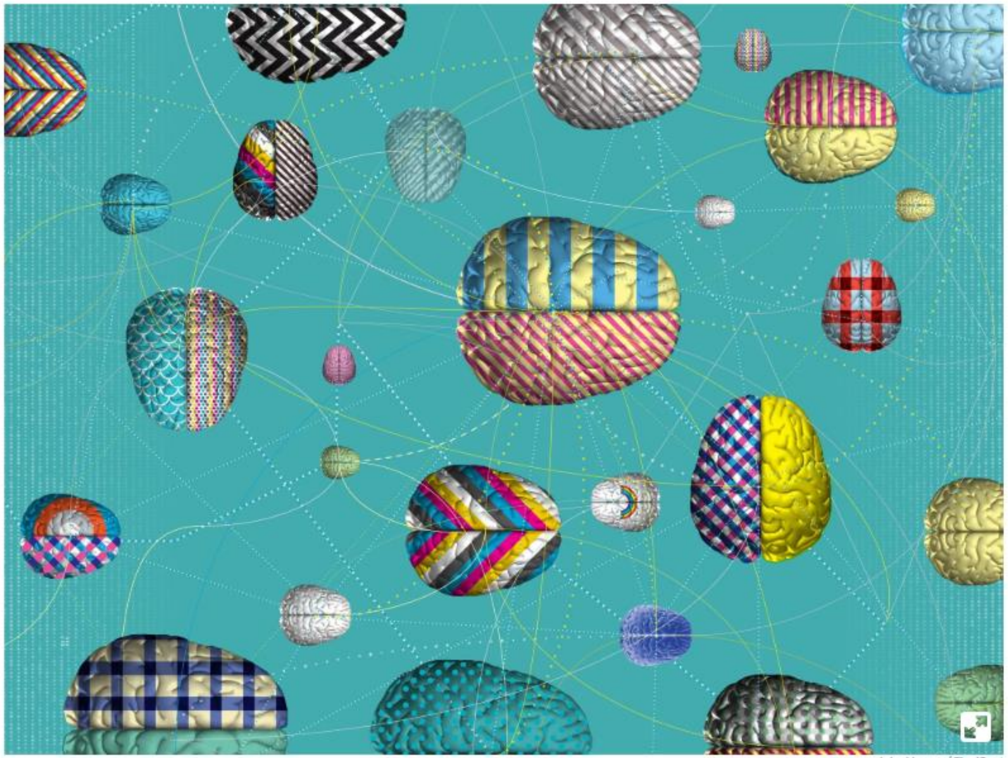
THE RESEARCH IS IN

Students Think Lectures Are Best, But Research Suggests They're Wrong

A study reveals students prefer low-effort learning strategies—like listening to lectures—despite doing better with active learning.

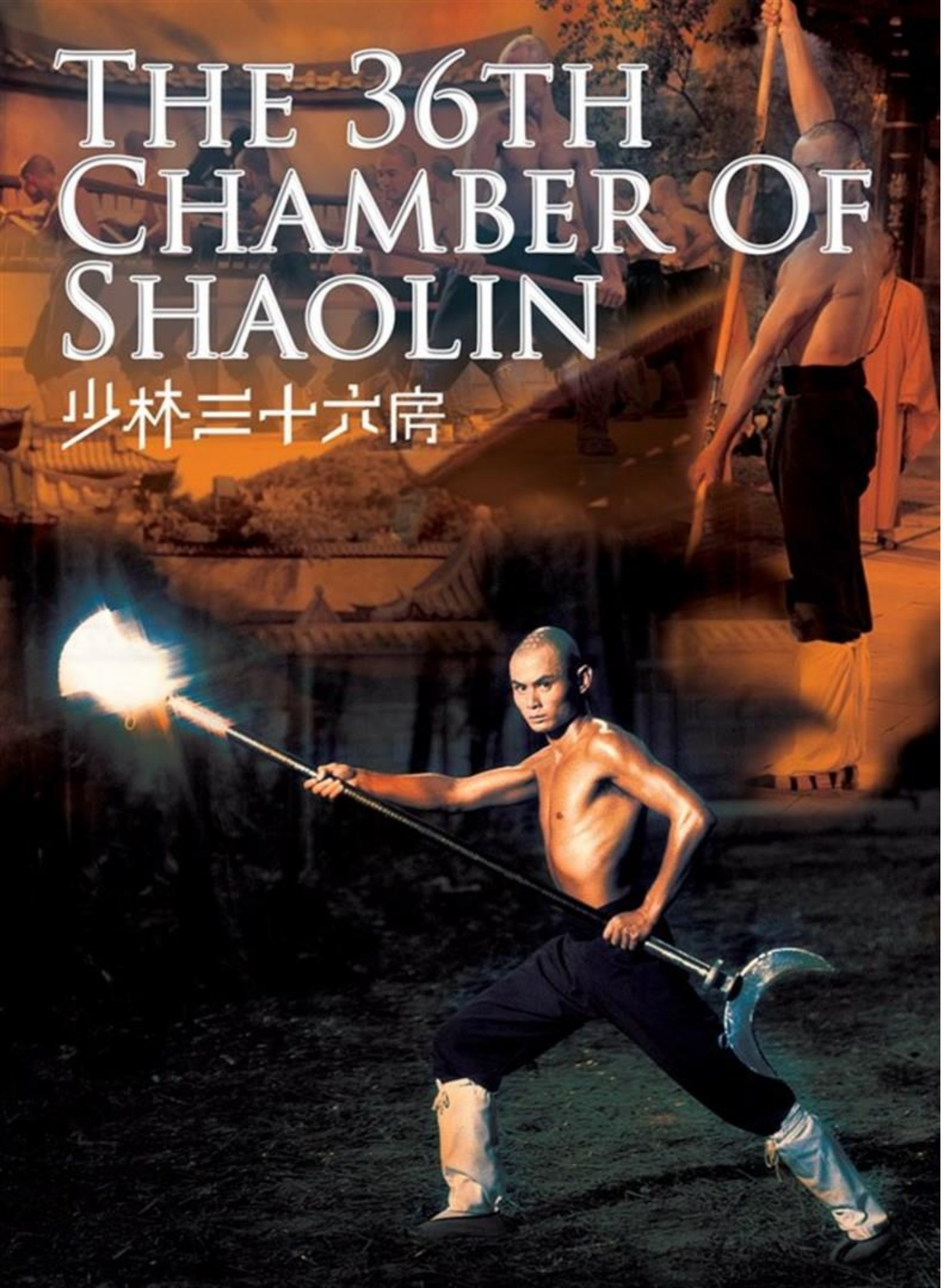
By Youki Terada

October 16, 2019



John Hersey / The iSpot

Students are often "poor judges" of their own learning, according to researchers in a study recently published in the ***Proceedings of the National Academy of Sciences***. Strategies that require low cognitive effort—such as passively listening to a lecture—are often perceived by students to be more effective than active strategies such as hands-on experimentation and group problem-solving. The group dynamic can make students feel frustrated and "painfully aware of their lack of understanding," but the study concluded that the more effort and struggle involved—hallmarks of a student-centered, active approach—the more students learned.



Teach kung fu to lay people

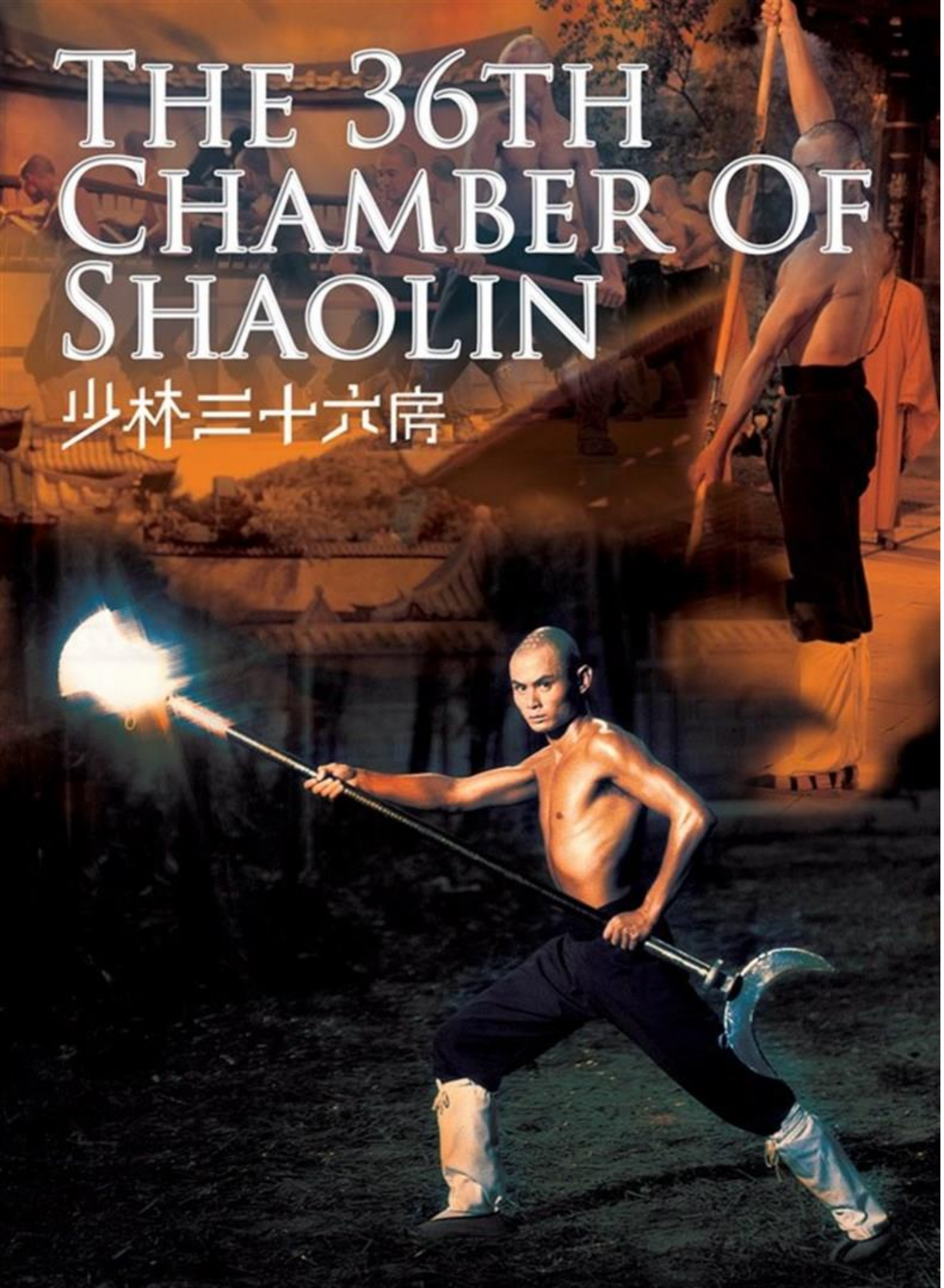
Philosophical training

Weapons

Leg, head strikes

Dexterity

Strength, balance



- Teach physics at MFF
- Nobel prize
- Overthrowing paradigms
- Finding your own topics
- Presentation of results
- Writing papers
- Reading papers
- Experimental techniques
- Integration
- Derivative/Taylor expansion
- Algebra

Question:

How fast does grass grow?