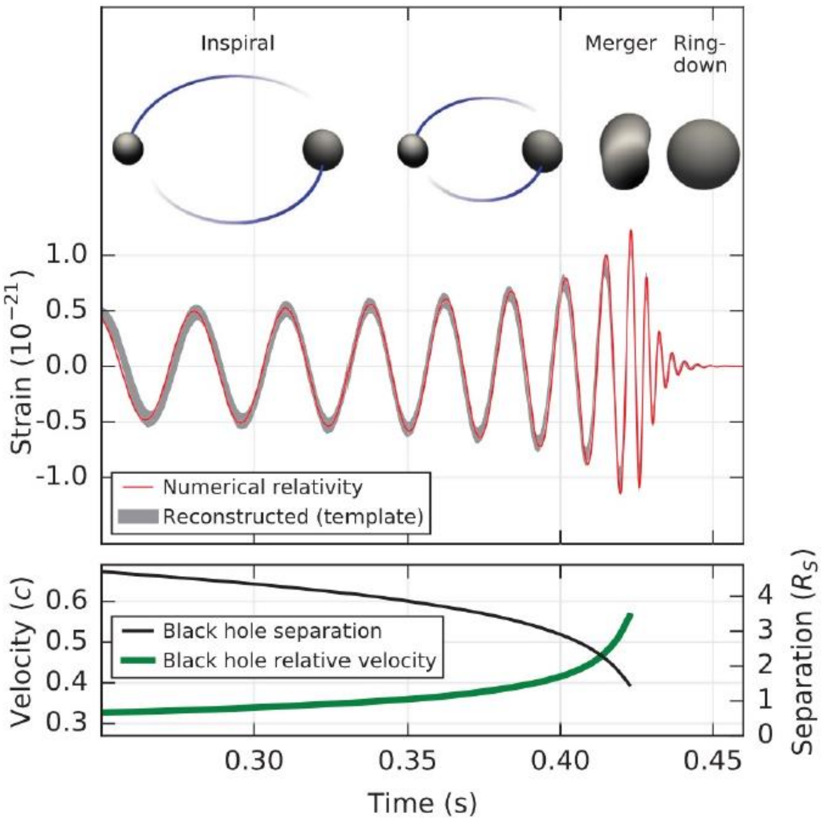
Astrophysics of gravitational wave sources

Lecture 12: Mergers & transients

Ondřej Pejcha

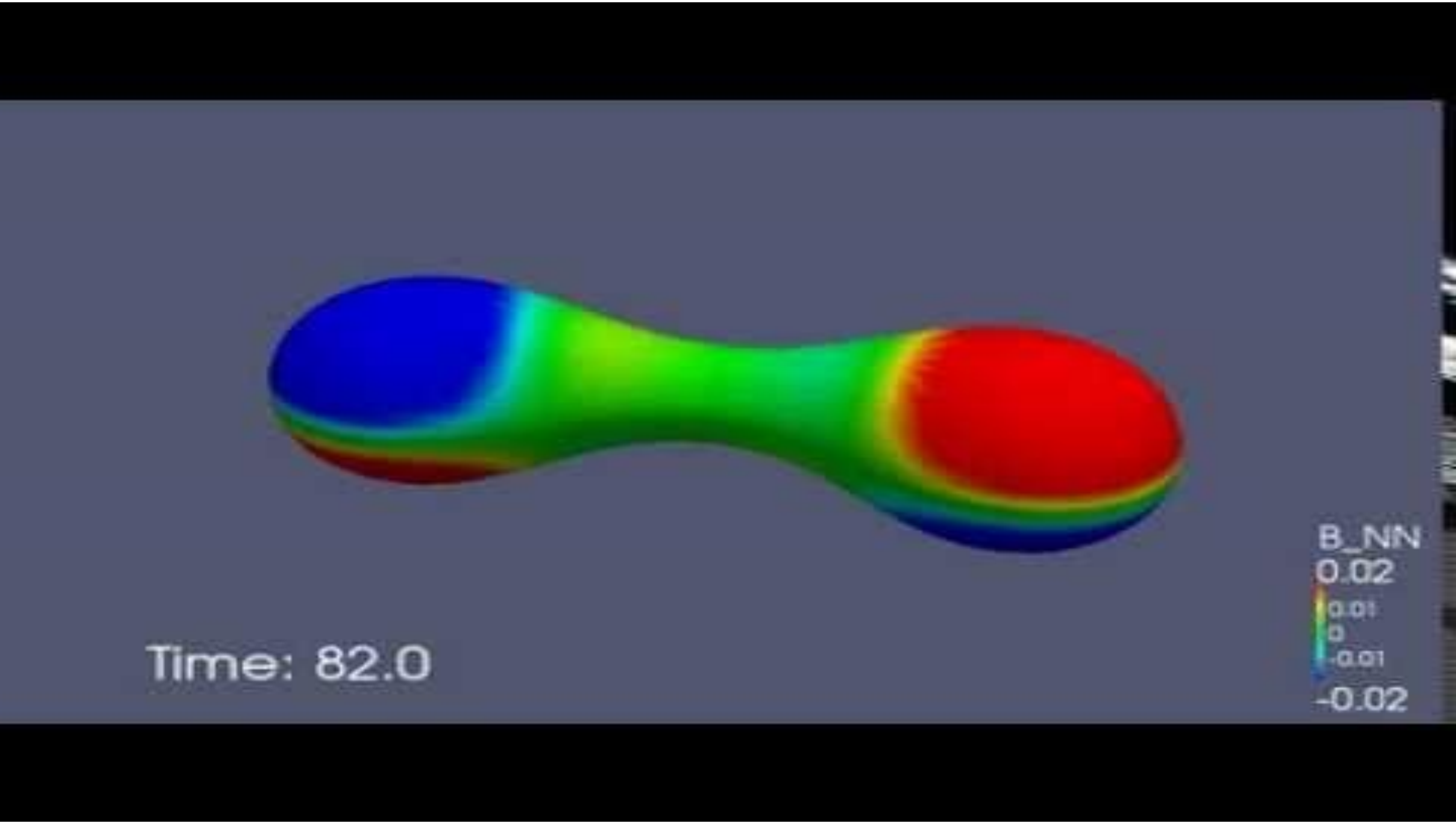
ÚTF MFF UK

Binary black hole mergers

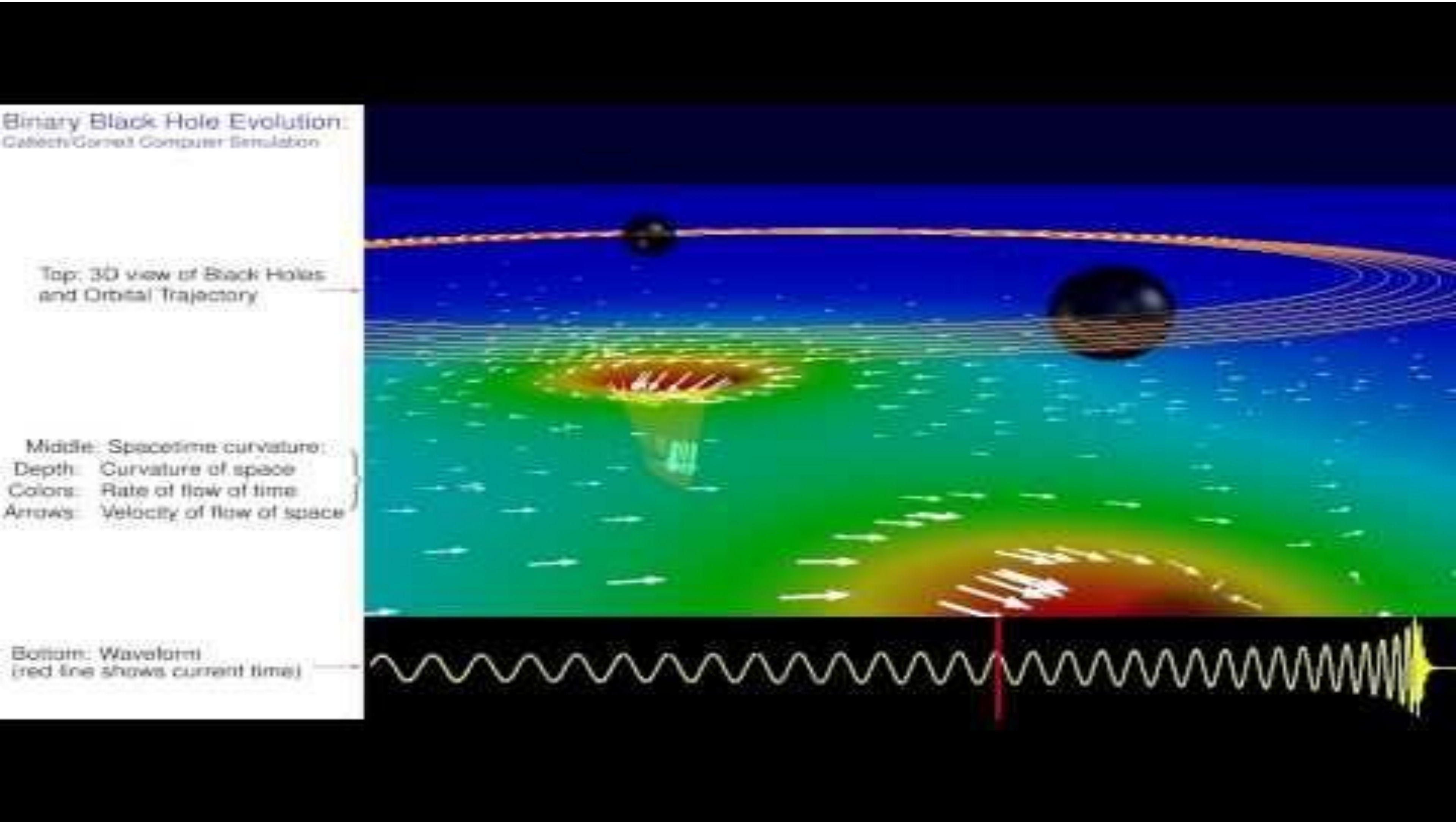


Abbott et al. (2016)

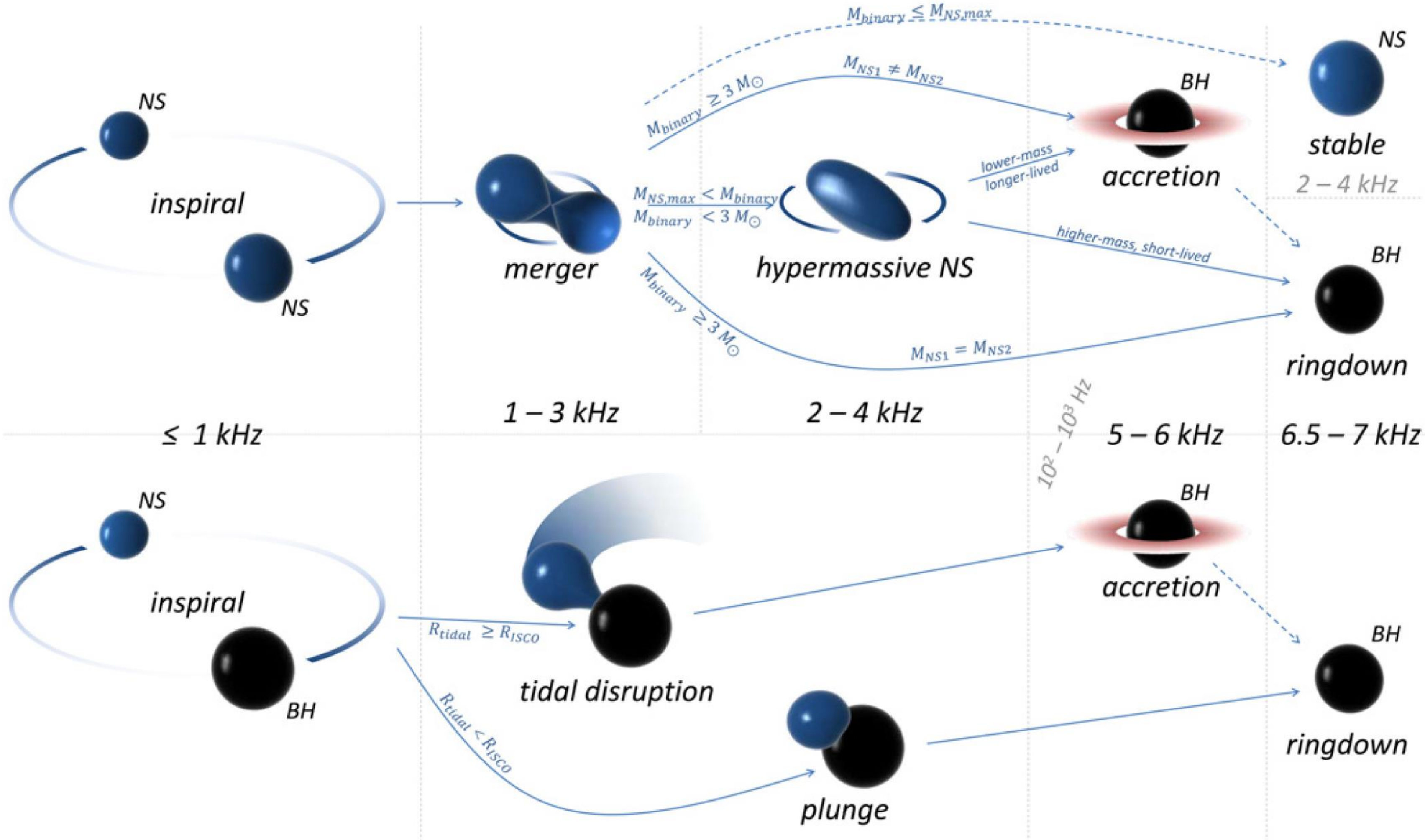
Black hole collision



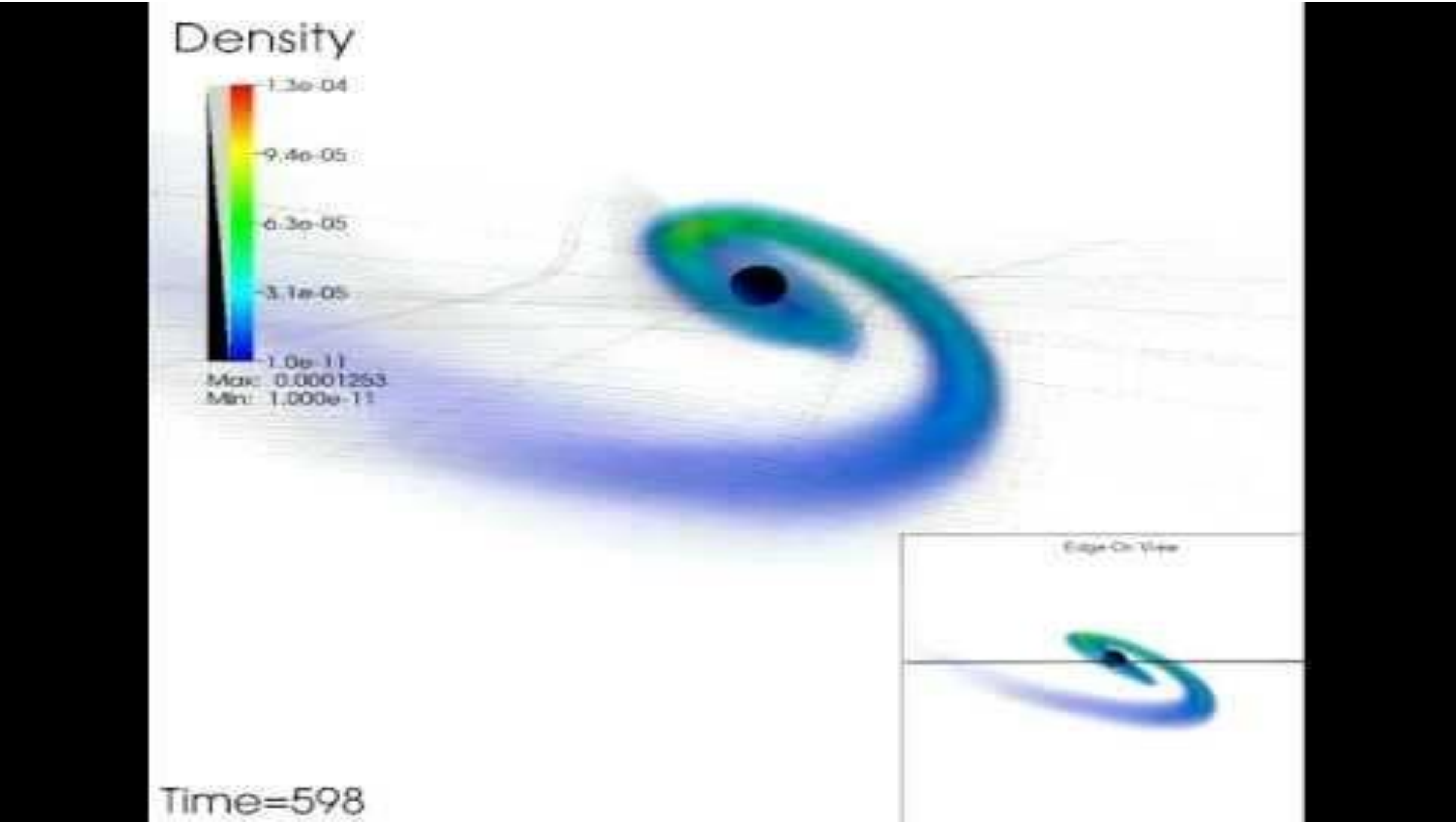
https://www.black-holes.org/



https://www.black-holes.org/

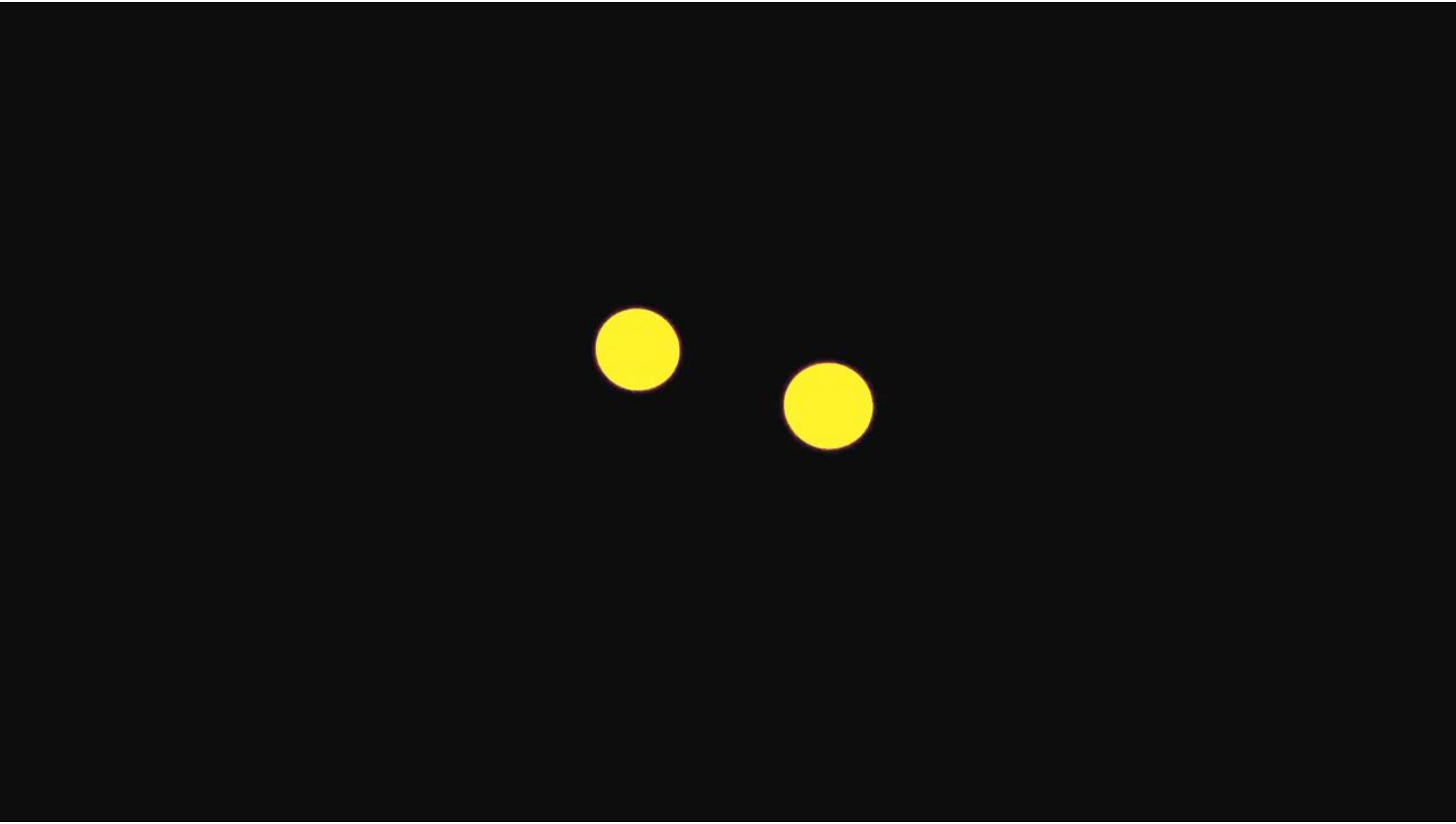


Bartos et al. (2013)



https://www.black-holes.org/

Binary neutron star merger



Radice et al.

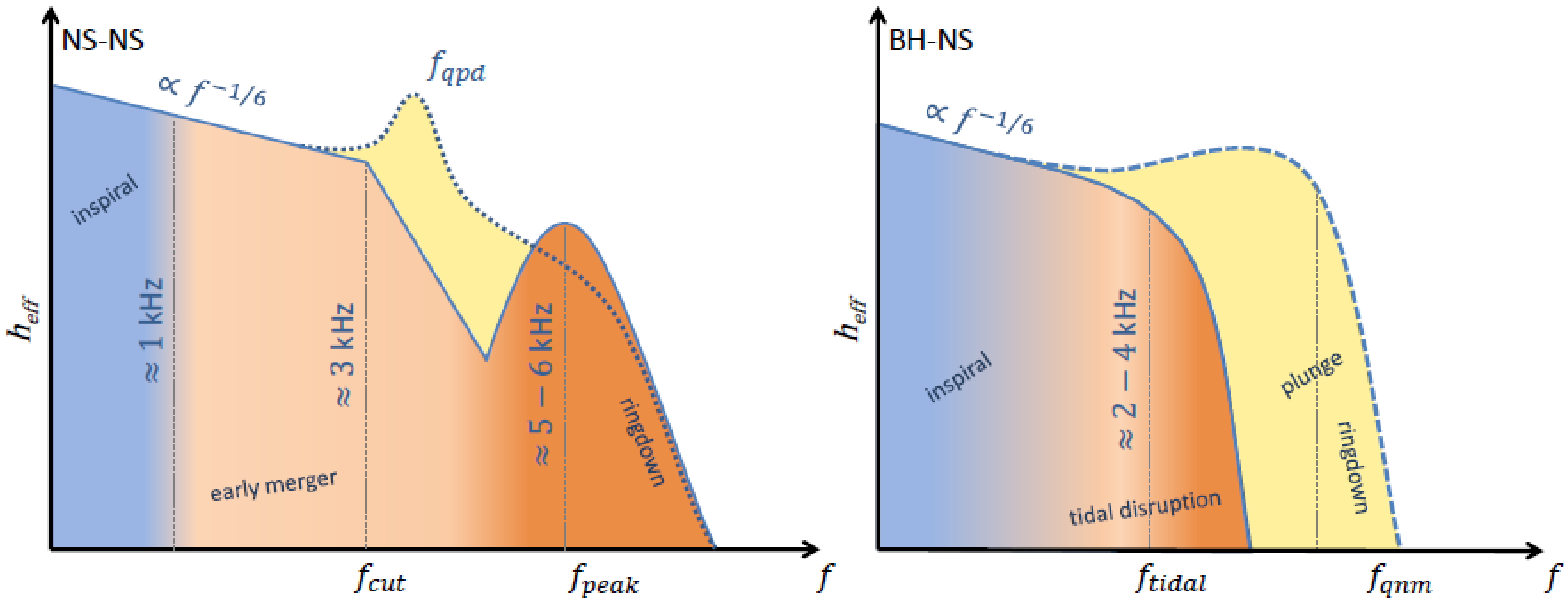


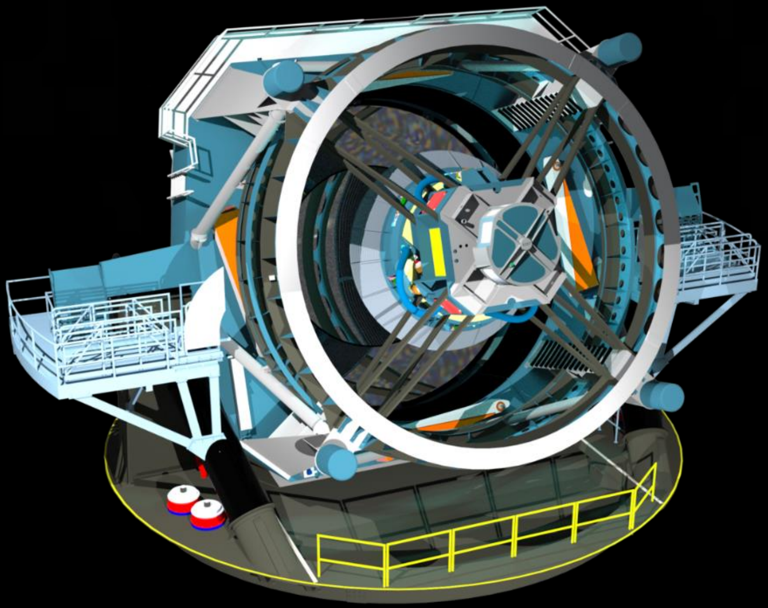
Figure 2. Schematic spectrum of effective amplitude $h_{\rm eff}$ for compact binary coalescences. **(left)** NS-NS binaries. During the inspiral phase up to $\approx 1\,$kHz and the early-merger phase up to $f_{\rm cut} \sim 3\,$kHz, the system retains its binary-like structure and $h_{\rm eff}$ scales as $f^{-1/6}$. If a BH is promptly formed, matter quickly falls in the BH, losing angular momentum through emitting GWs around a peak frequency $f_{\rm peak} \sim 5-6\,$kHz. If a protoneutron star is formed from a NS-NS binary, it will radiate GWs through its quasiperiodic rotation at $f_{\rm qpd} \sim 2-4\,$kHz. After matter falls into the BH, the BH rings down, emitting GWs at $\approx 6.5-7\,$kHz with exponentially decaying amplitude. **(right)** BH-NS binaries. During the inspiral phase, $h_{\rm eff}$ scales as $f^{-1/6}$. If the NS is tidally disrupted before reaching the ISCO, GW emission will cut off at $f_{\rm tidal} \sim 2-4\,$kHz, i.e. the GW frequency at tidal disruption [66, 67]. If the NS plunges into the BH without being tidally disrupted, the plunge cuts off GW emission from the binary and excites the quasinormal mode of the remaining BH, which rings down emitting GWs at frequency $f_{\rm qnm}$ (NS-NS representation was partially inspired by Kiuchi et al. [61]; BH-NS representation is based on Kyutoku et al. [66]).

Bartos et al. (2013)

Physics of astronomical transients

- What is the luminosity and duration of the transient (=brightening) from the destruction of Thor's hammer?

- Can we detect signatures of clashing superheros with Vera Rubin Telescope?



Nuclear statistical equilibrium

$$Y_i = G_i(\rho N_A)^{A_i-1} \frac{A_i^{3/2}}{2^{A_i}} \left(\frac{2\pi\hbar^2}{m_u k_b T}\right)^{3/2(A_i-1)} \exp(B_i/k_b T) Y_n^{N_i} Y_p^{Z_i}.$$

Thielemann et al. (2017)

As a function of time, NSE follows density, temperature and Ye

very high densities favor large nuclei, due to the high power of ρ^{A_i-1}

very high temperatures favor light nuclei, due to $(k_b T)^{-3/2(A_i-1)}$

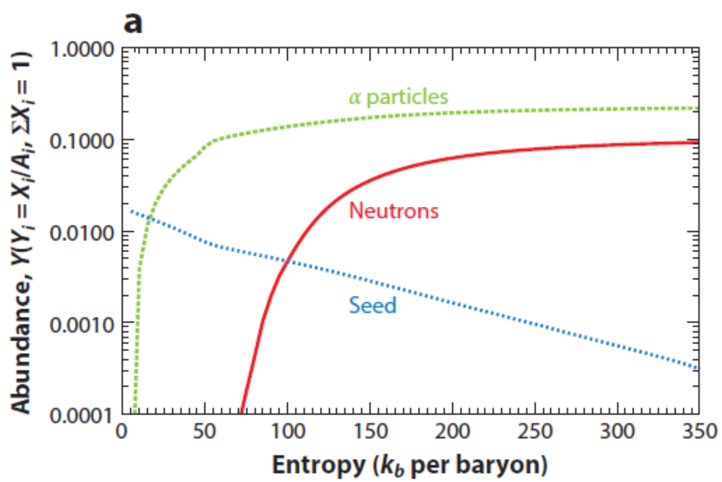
intermediate regime, $\exp(B_i/k_b T)$ favors tightly bound nuclei

$$\frac{\mathrm{BE}}{A \cdot \mathrm{MeV}} = a - \frac{b}{A^{1/3}} - \frac{cZ^2}{A^{4/3}} - \frac{d(N-Z)^2}{A^2} \pm \frac{e}{A^{7/4}}$$

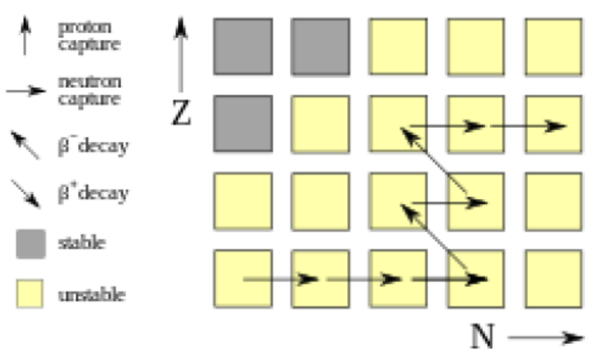
$\alpha + \alpha + \alpha \rightarrow {}^{12}\mathrm{C}$ or $\alpha + \alpha + n \rightarrow {}^{9}\mathrm{Be}$

Bottleneck, works only at high density

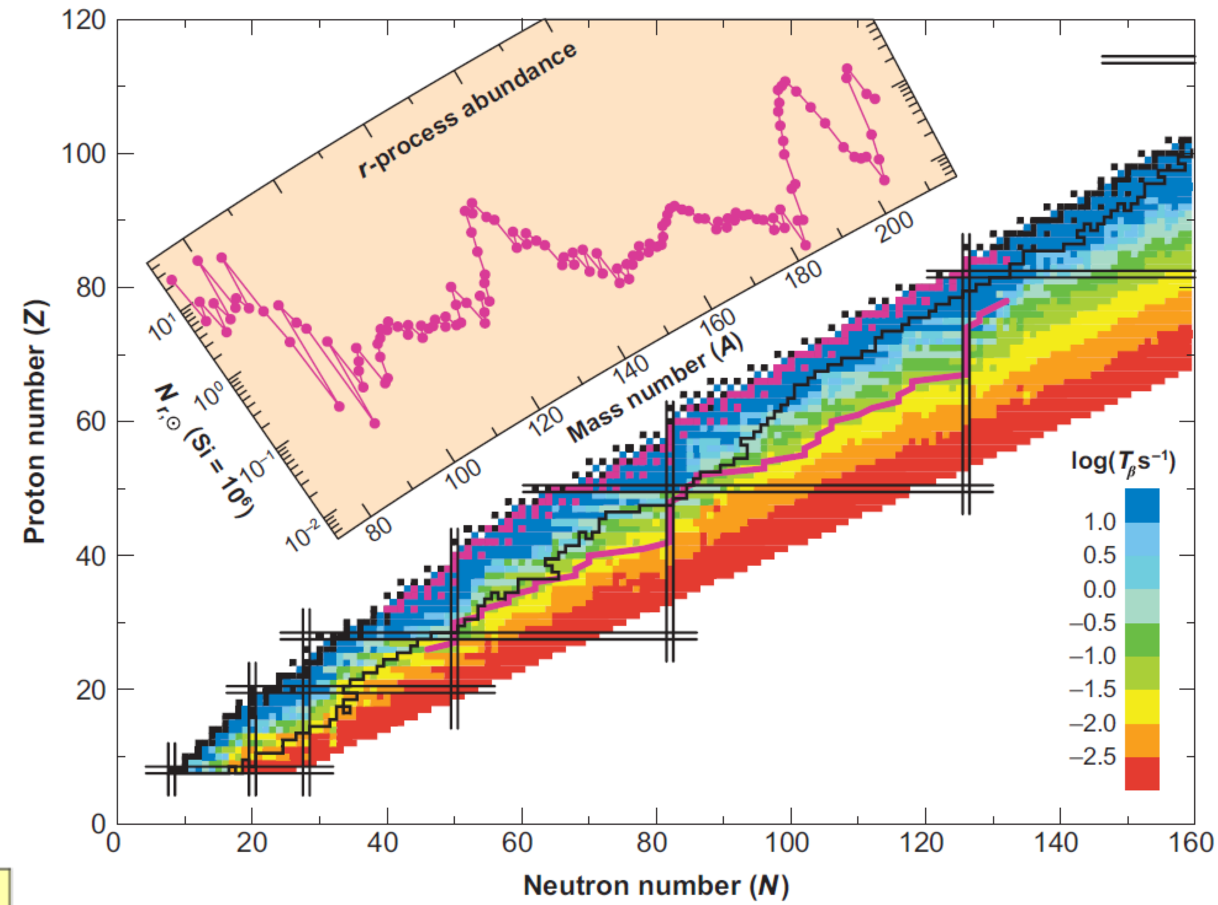
At low density: alpha-rich freezeout: H, He, A~90



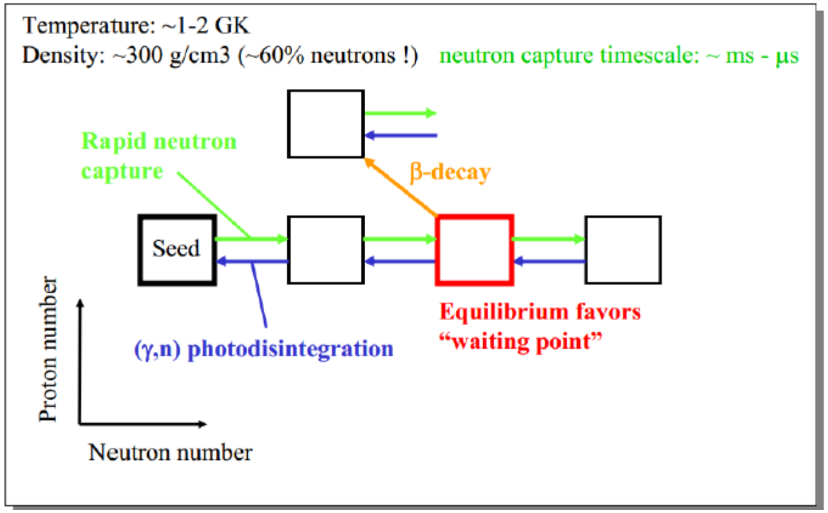
r-process
rapid neutron captures
$X(n,\gamma)Y$



synthesis of neutron-rich nuclei
A > 60

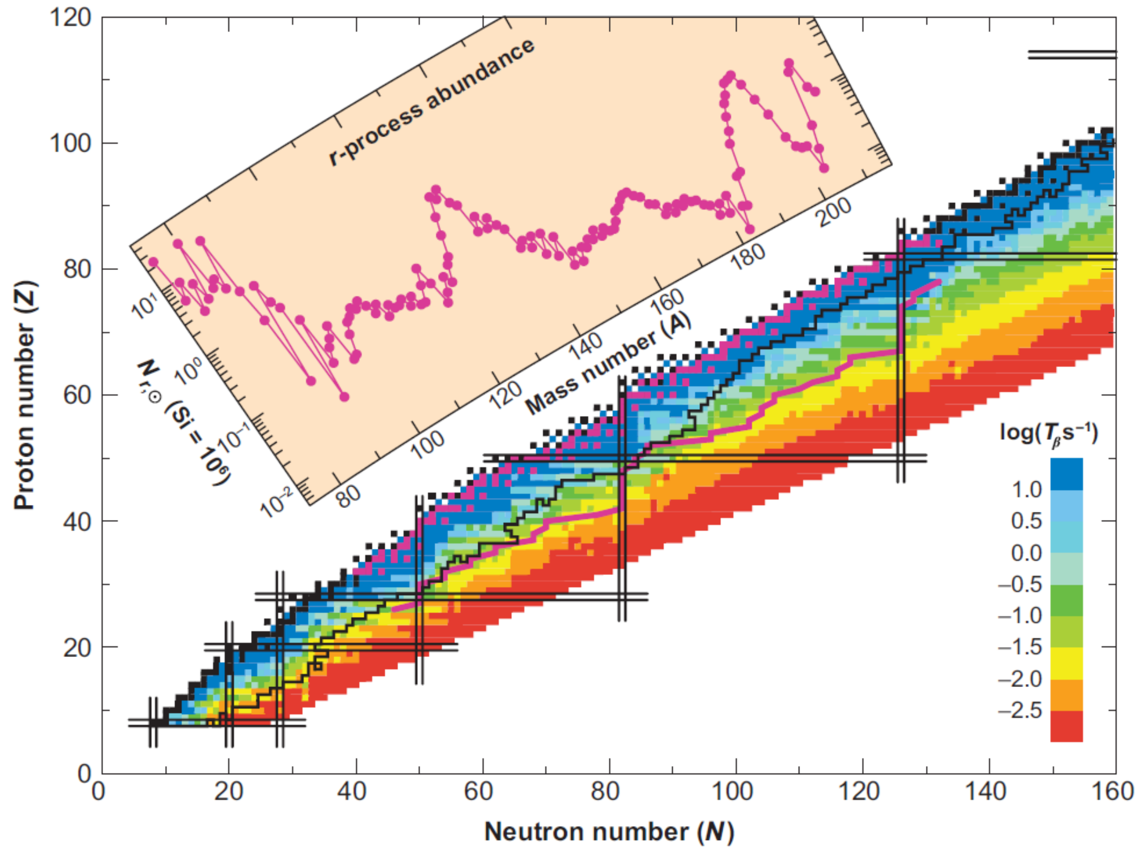


Sneden et al. (2008)

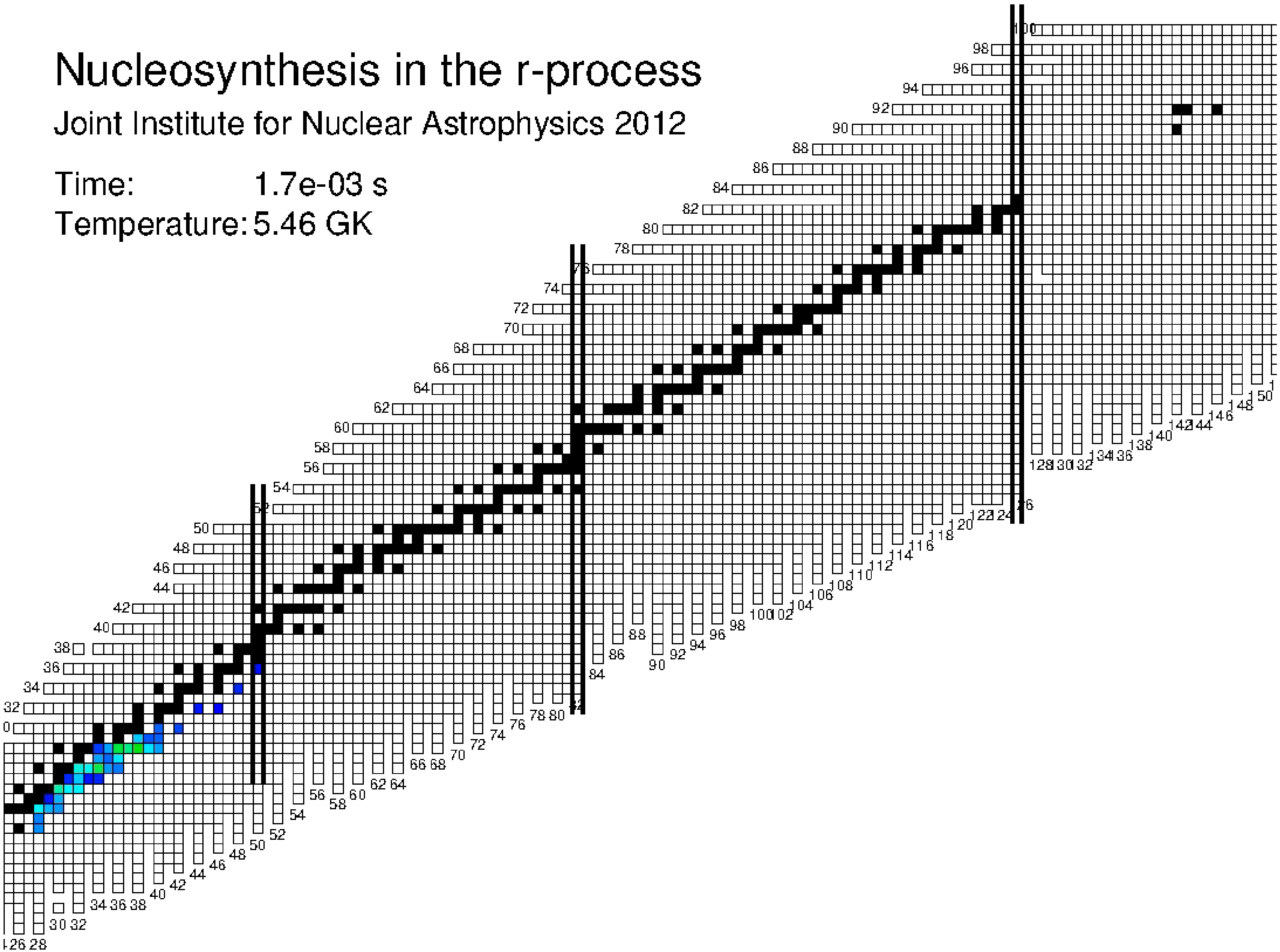


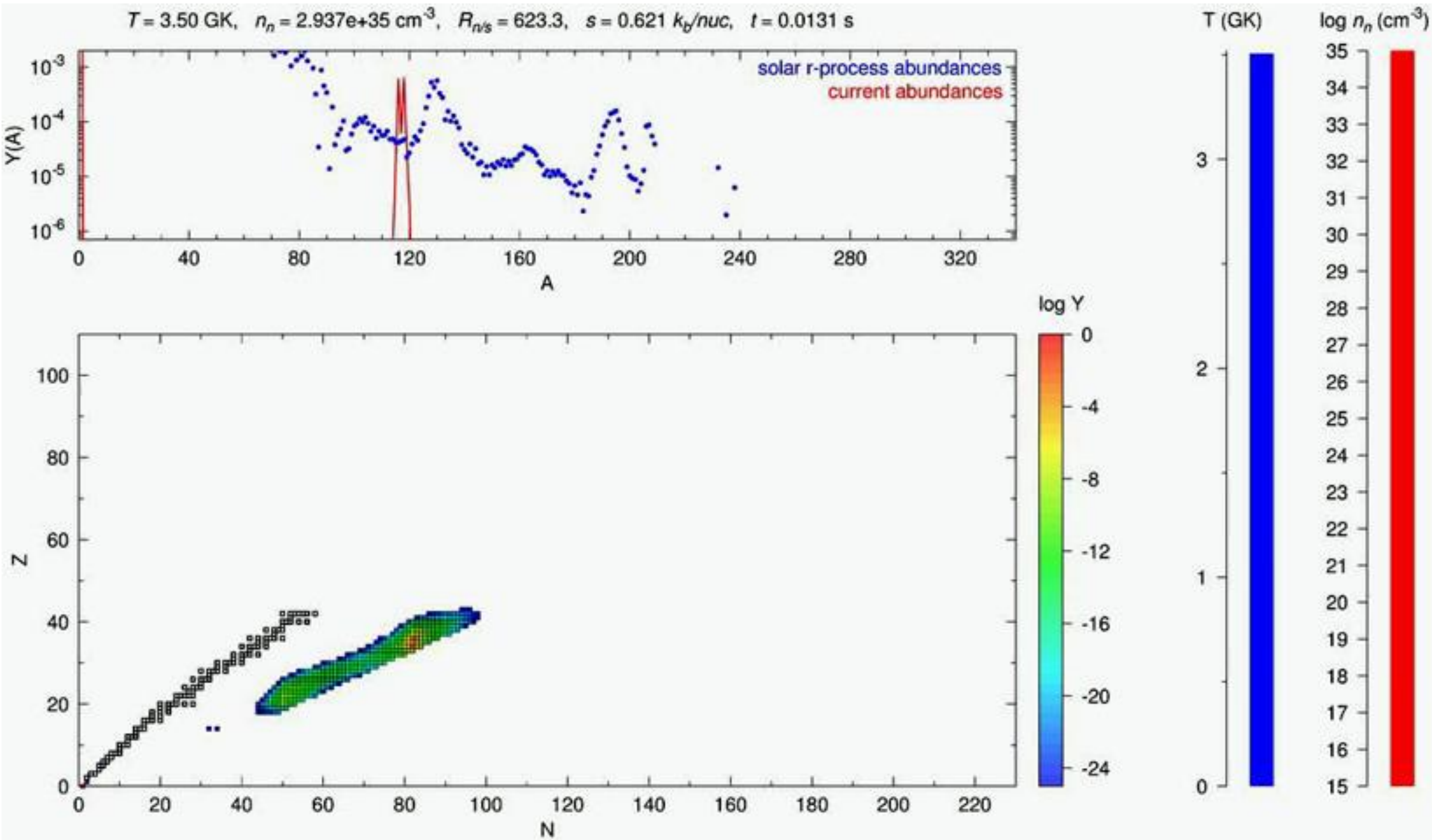
https://www.asc.ohio-state.edu/physics/ntg/6805/slides/rprocess.pdf

Fission terminates r-process -> recycling



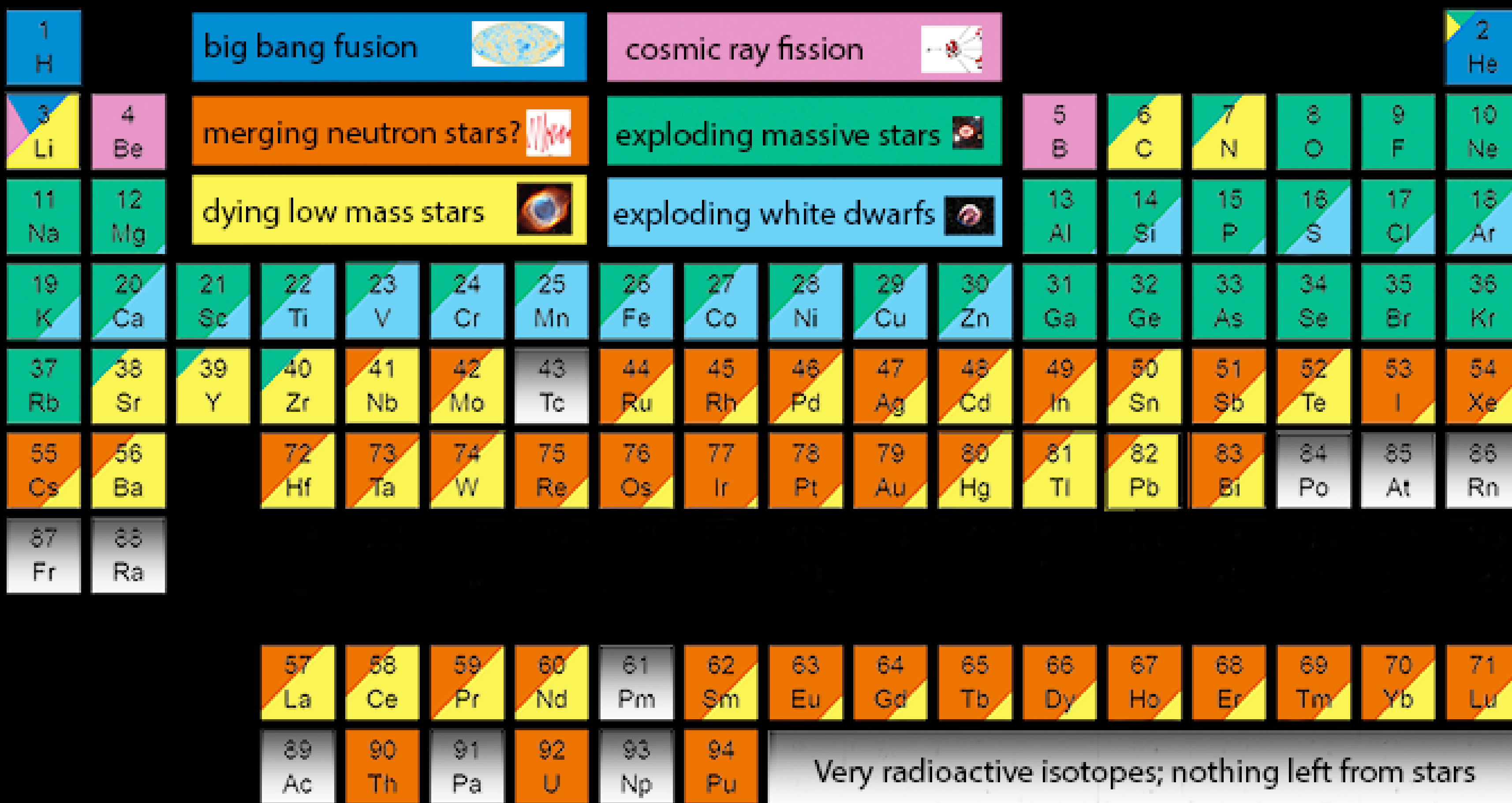
R process


Nucleosynthesis in the r-process
Joint Institute for Nuclear Astrophysics 2012
Time: 1.7e-03 s
Temperature: 5.46 GK



https://www.youtube.com/watch?v=T44B9j3Vzxw

The Origin of the Solar System Elements



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

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