# The Equation of State of Ultra-Dense Matter and its Implication for the Diffuse Neutrino Background

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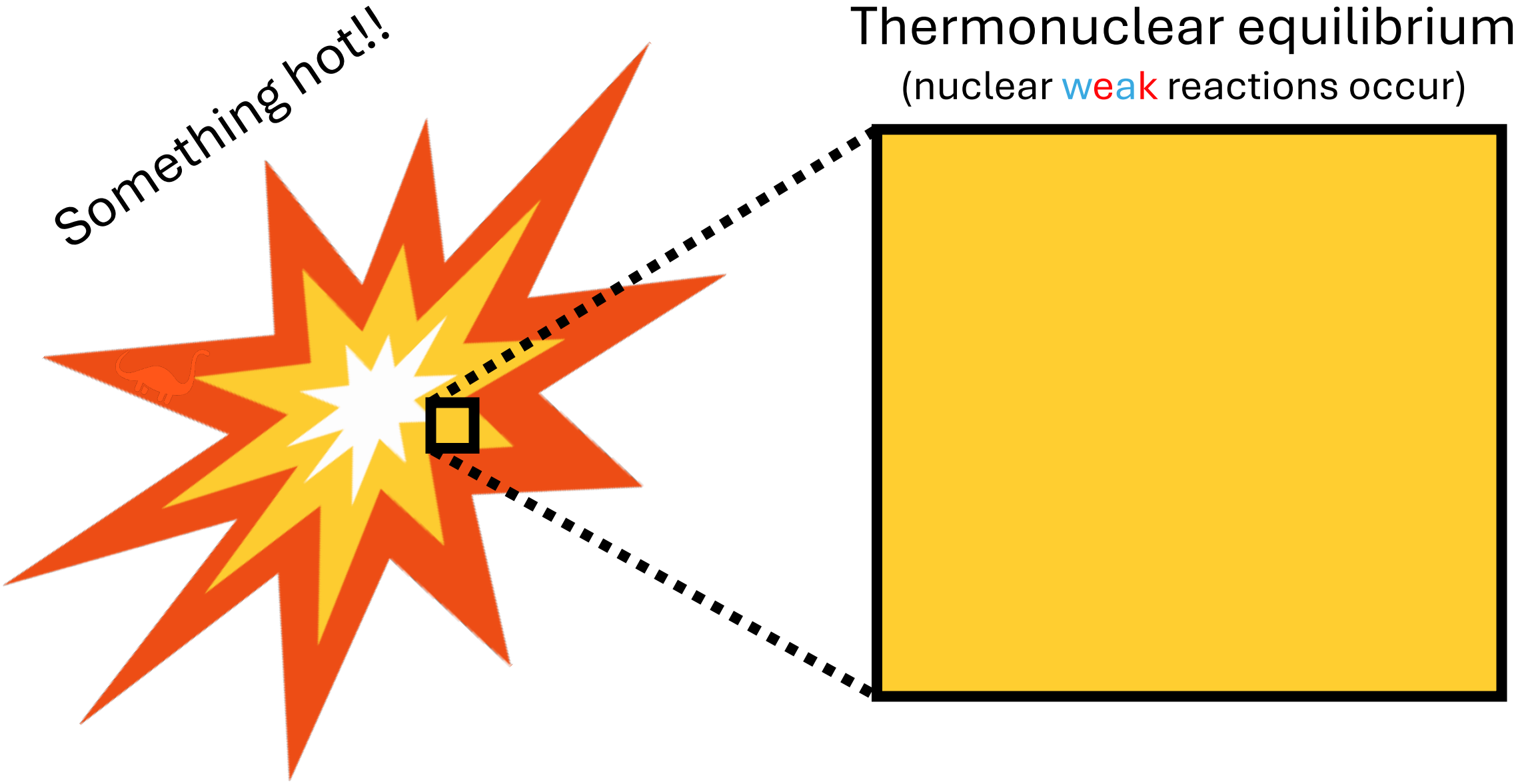
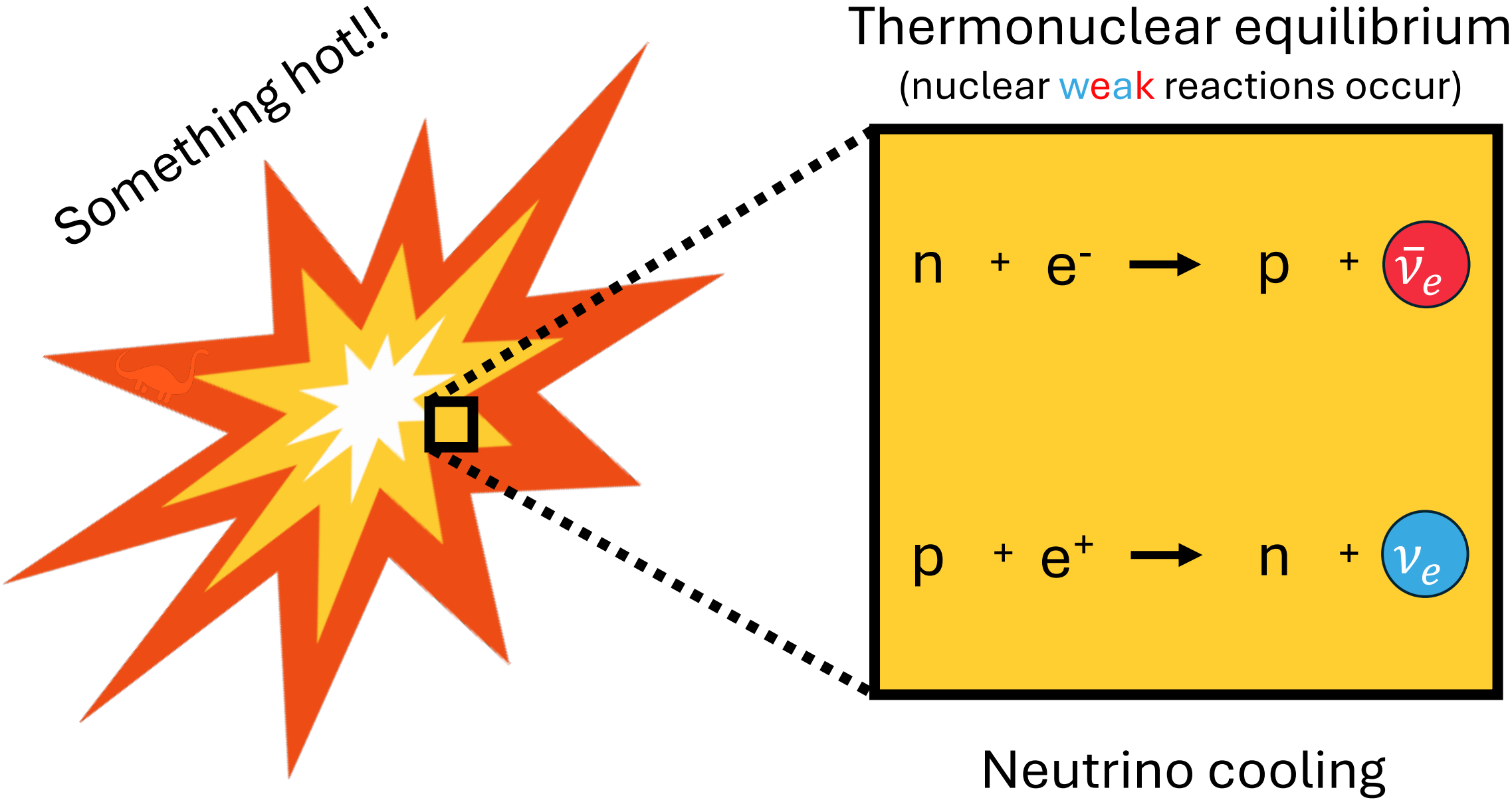
University of Guelph

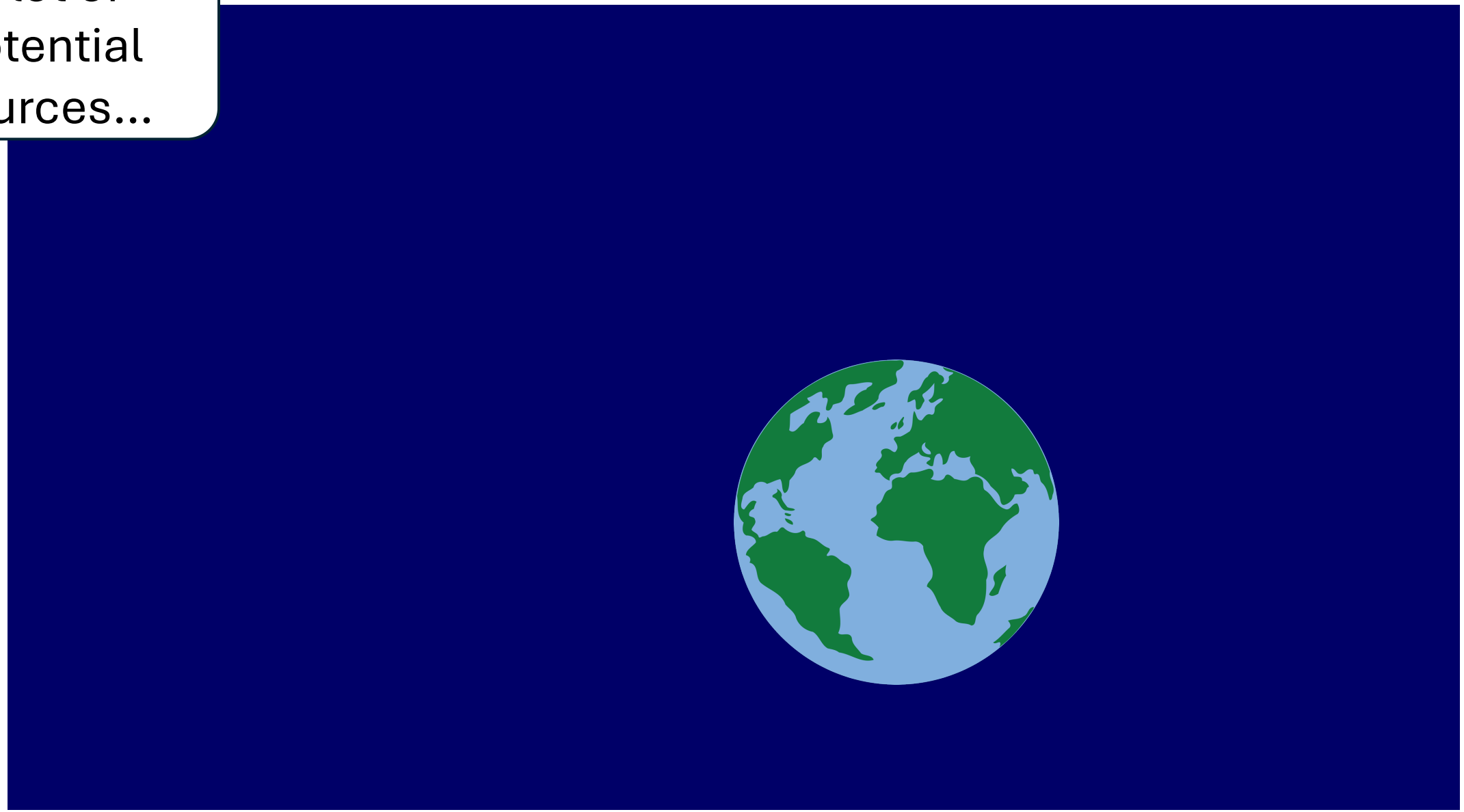
2024 CAP Congress


- Supernova
- Core of the sun
- Black hole accretion disk
- Binary neutron star merger
- …


Something hot!!
Thermonuclear equilibrium
(nuclear weak reactions occur)


Something hot!!
Thermonuclear equilibrium
(nuclear weak reactions occur)
n + e⁻ → p + $\bar{\nu}_e$
p + e⁺ → n + $\nu_e$
Neutrino cooling

A lot of potential sources...



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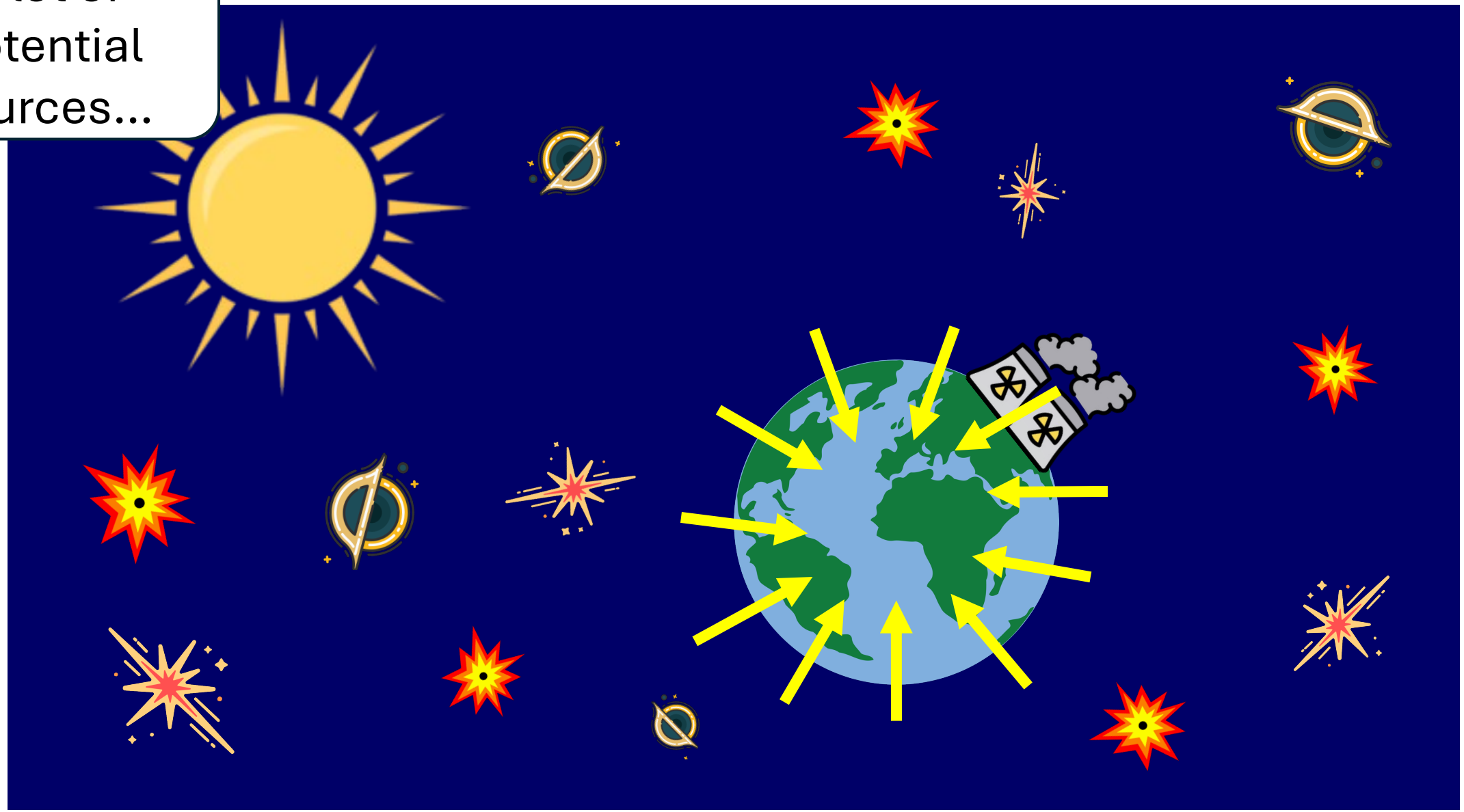
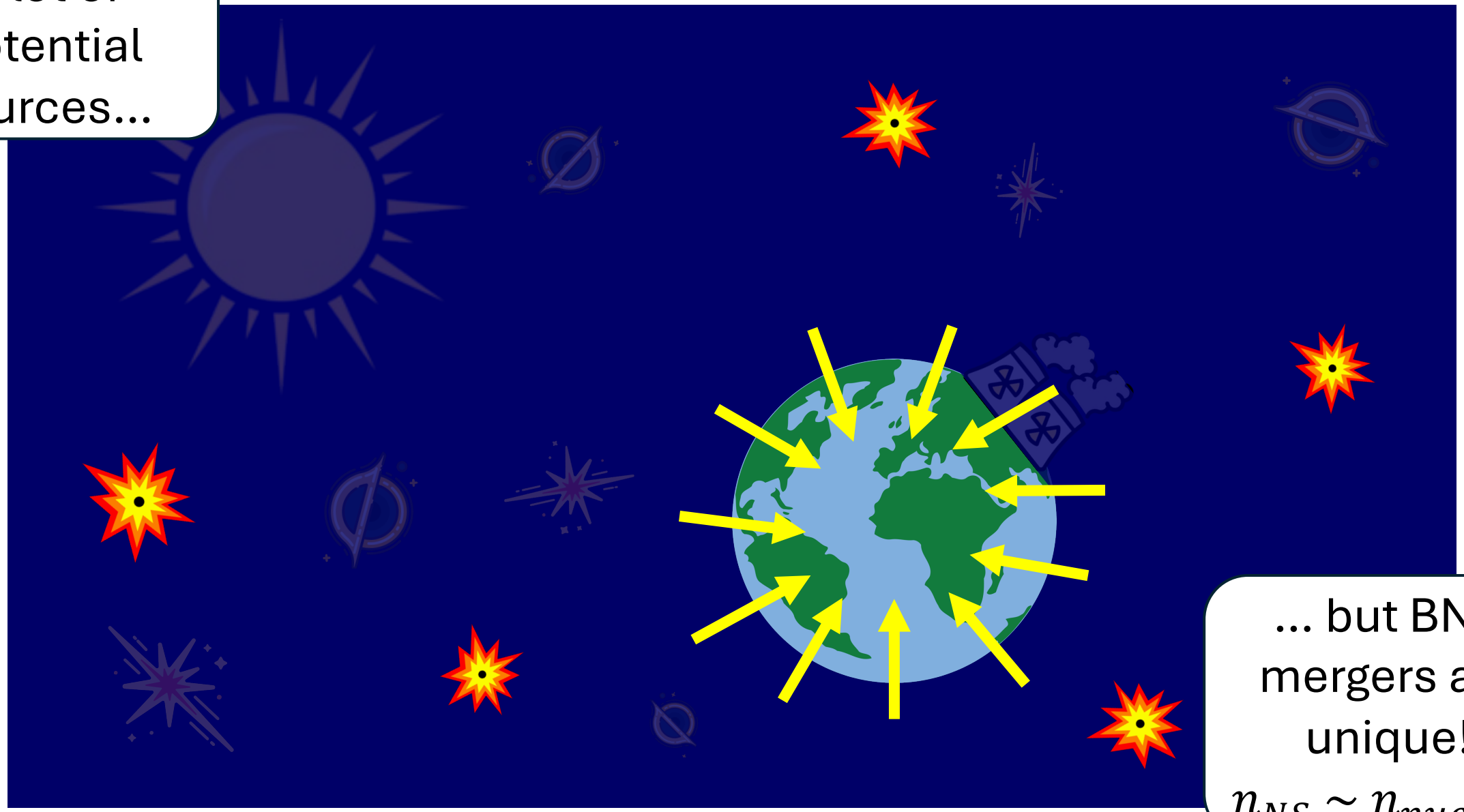


A lot of potential sources...



... but BNS mergers are unique!

$n_{NS} \sim n_{nucleus}$

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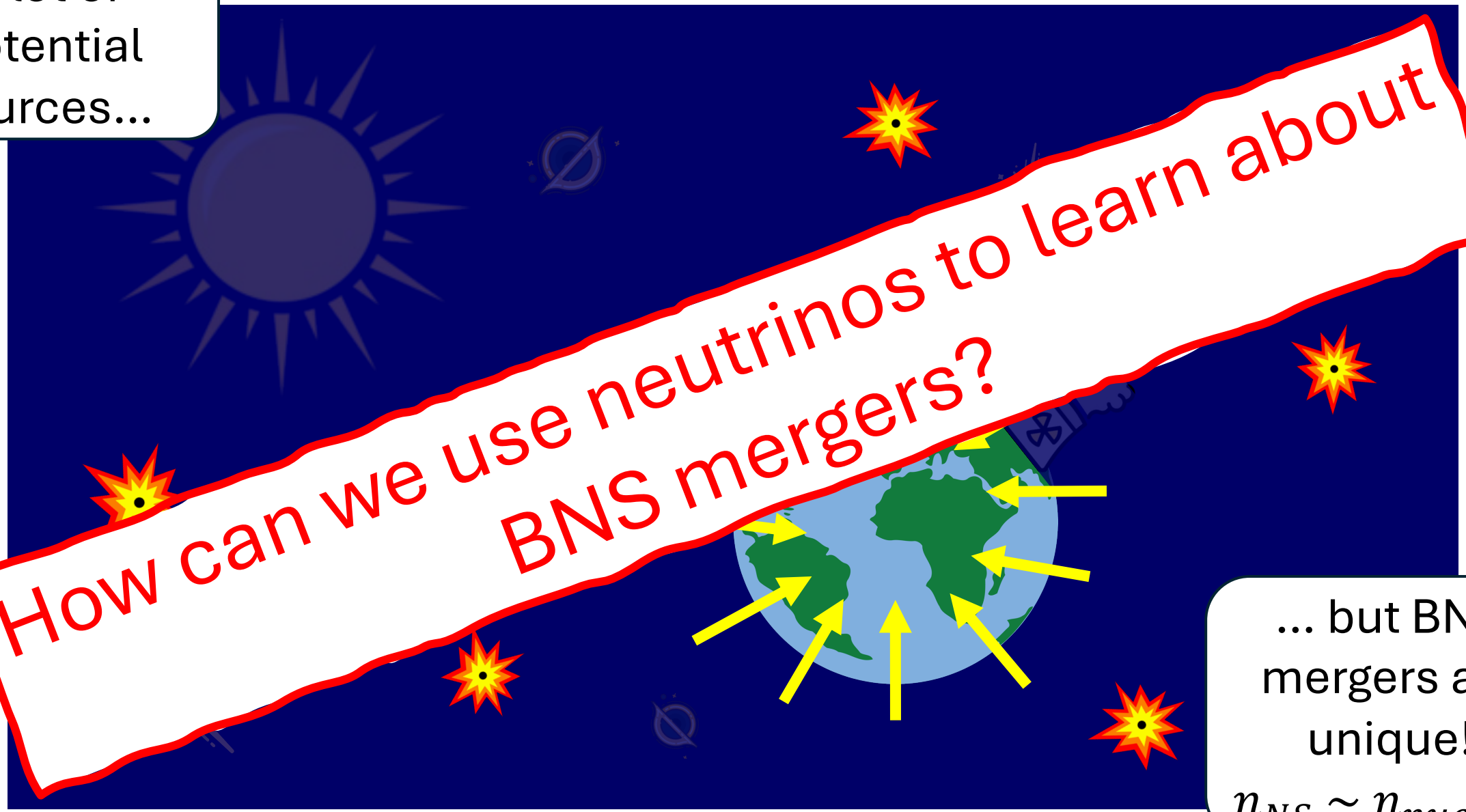
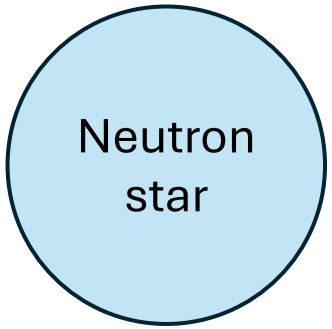
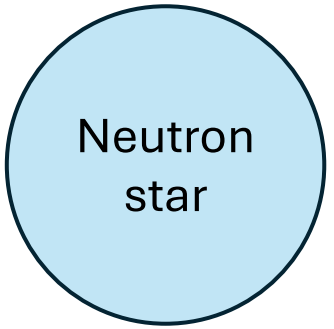


How can we use neutrinos to learn about BNS mergers?

... but BNS mergers are unique!

$n_{NS} \sim n_{nucleus}$


Neutron
star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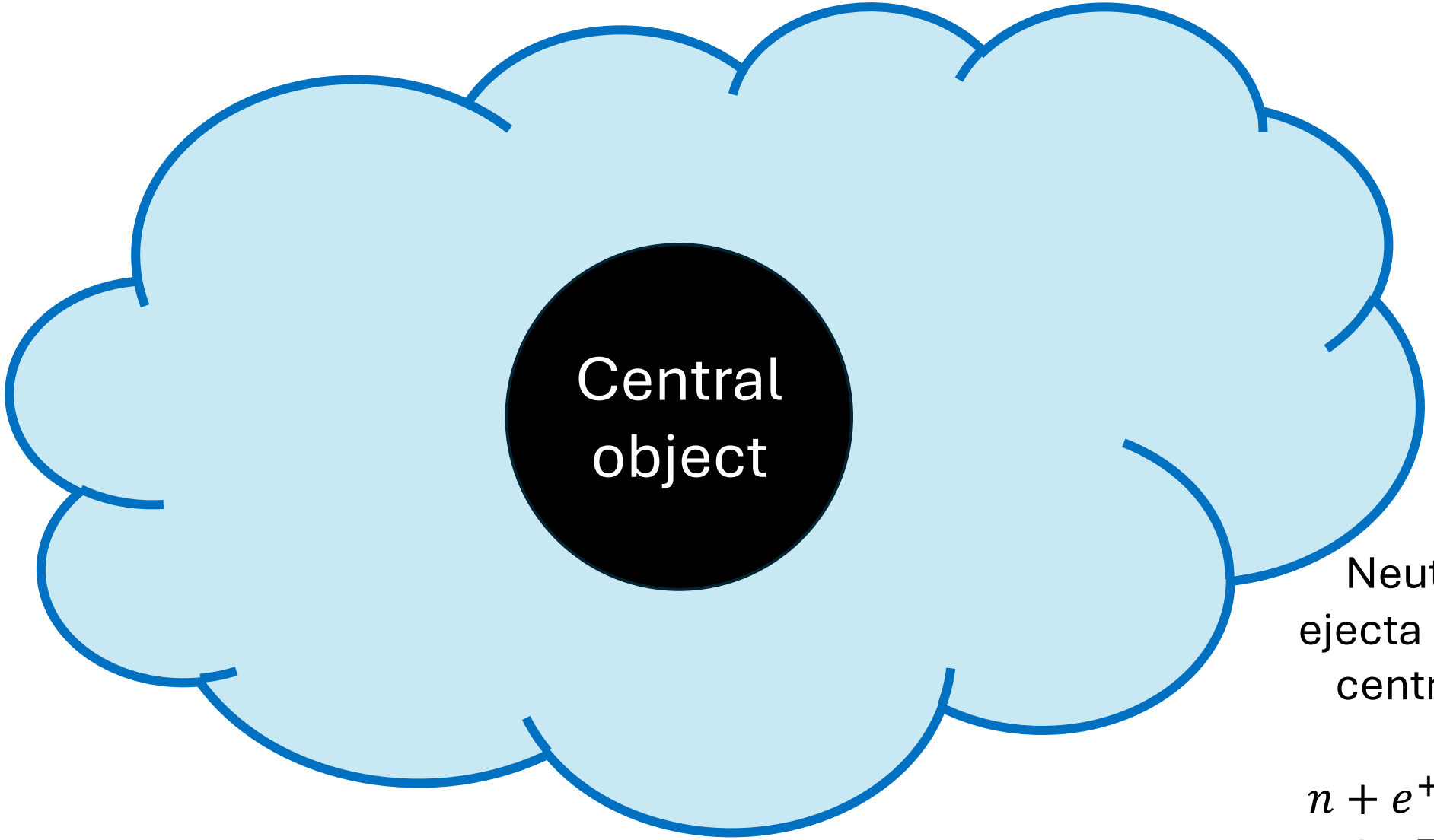
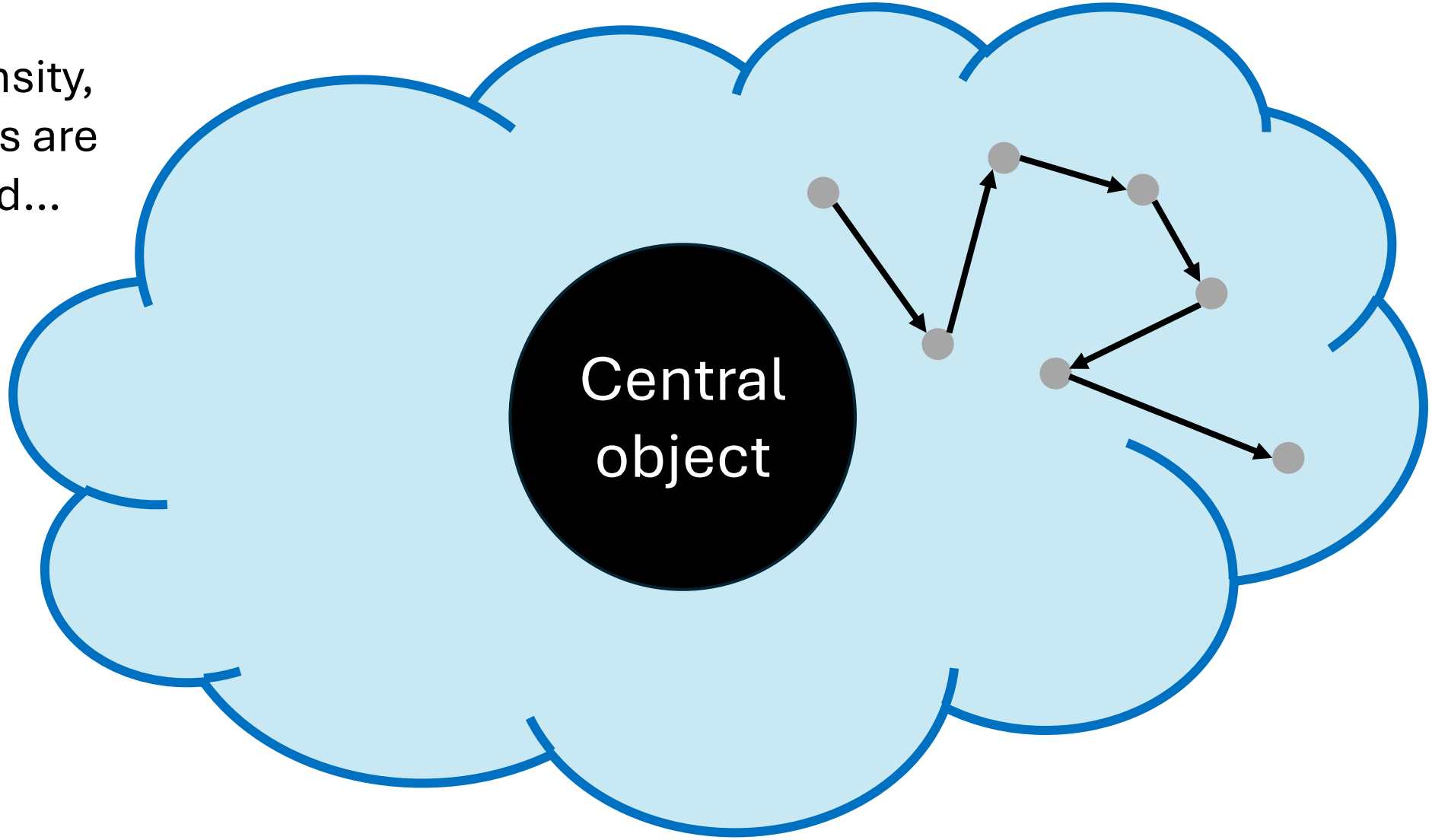
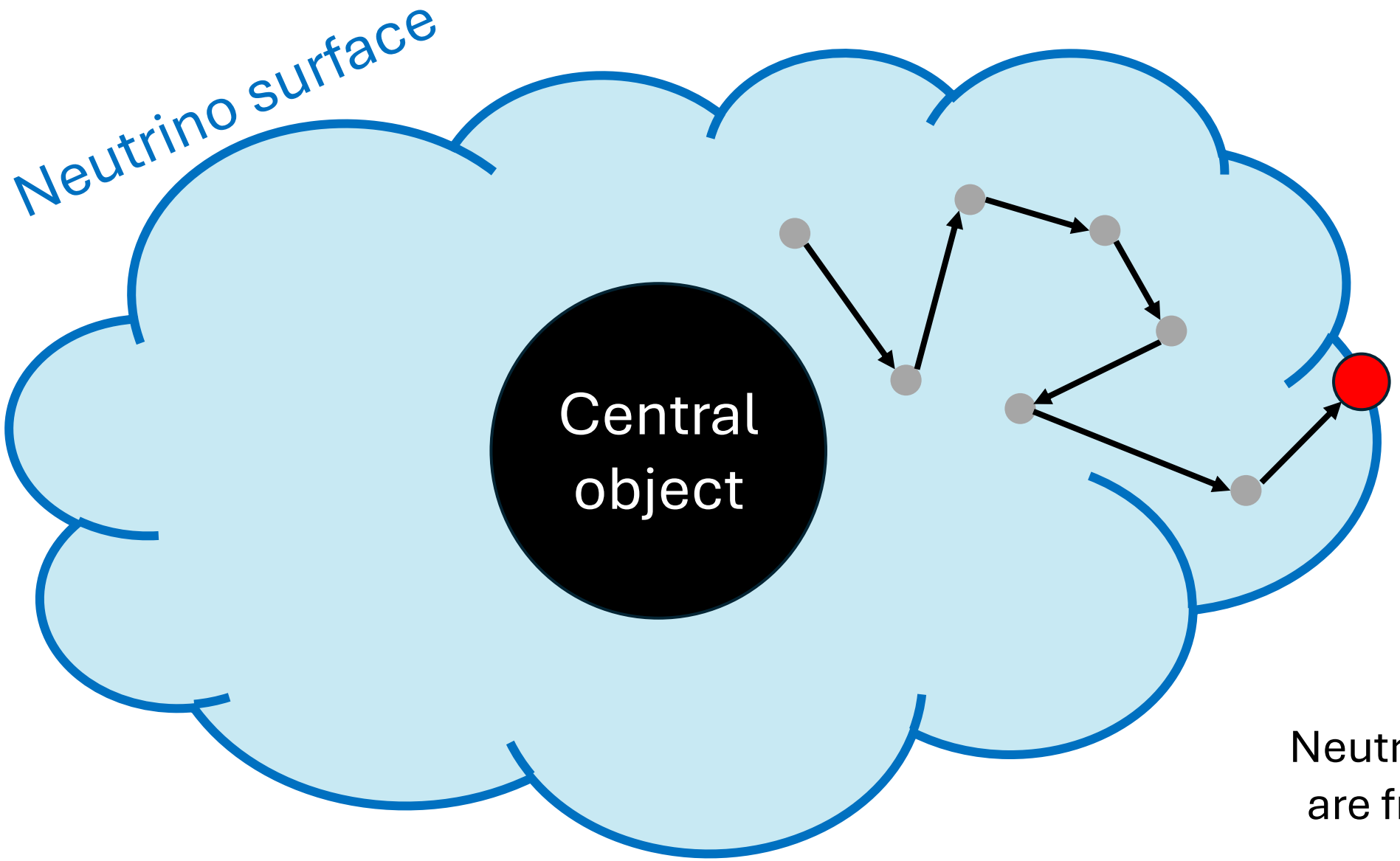



Neutron-rich ejecta around the central object

$$n + e^{+} \leftrightarrow p + \bar{\nu}_e$$
$$p + e^{-} \leftrightarrow n + \nu_e$$

High density, neutrinos are trapped…



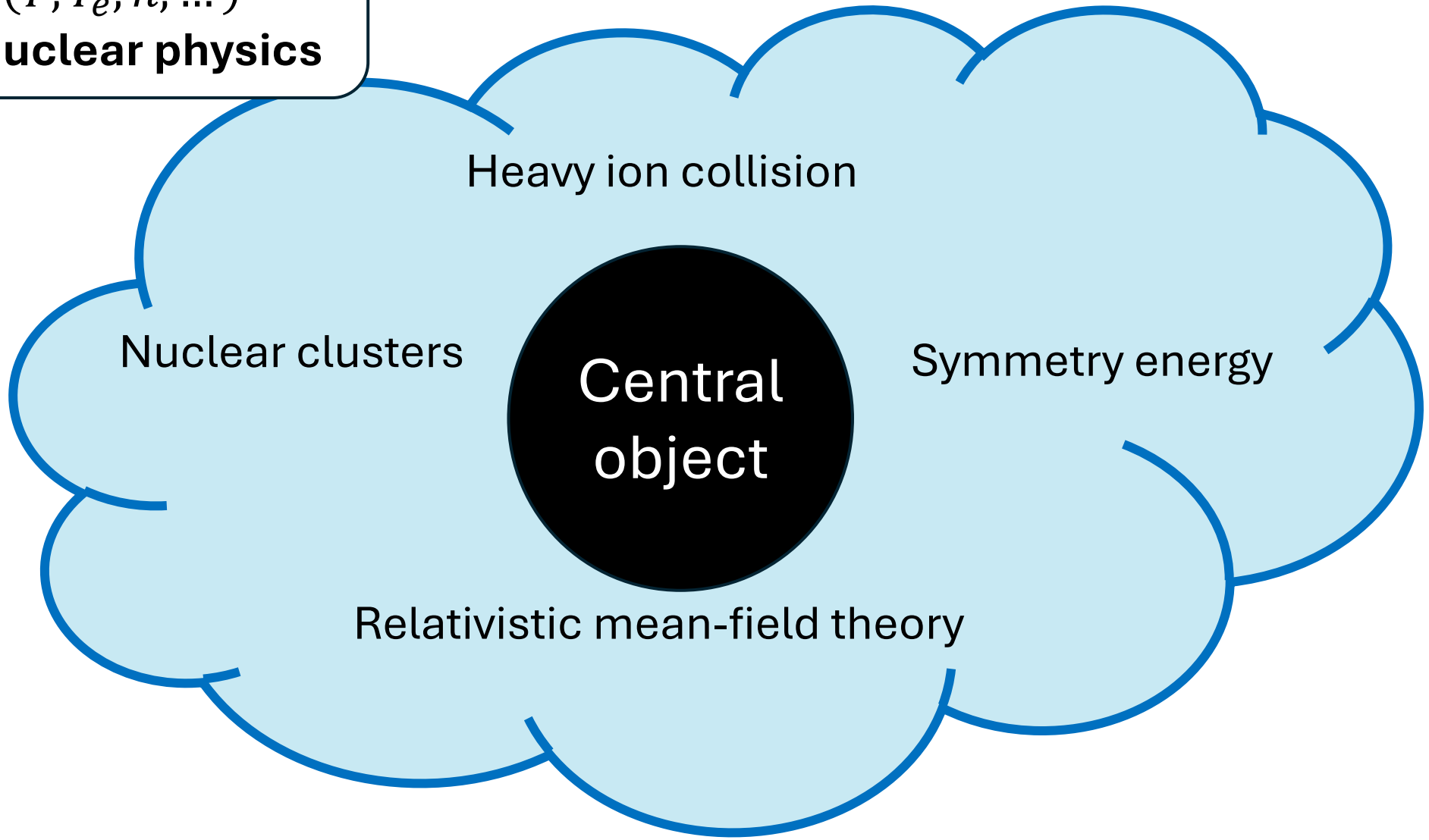



Neutrinos are free!

Equation of state

$P = P(T, Y_e, n, \dots)$

**Input of nuclear physics**



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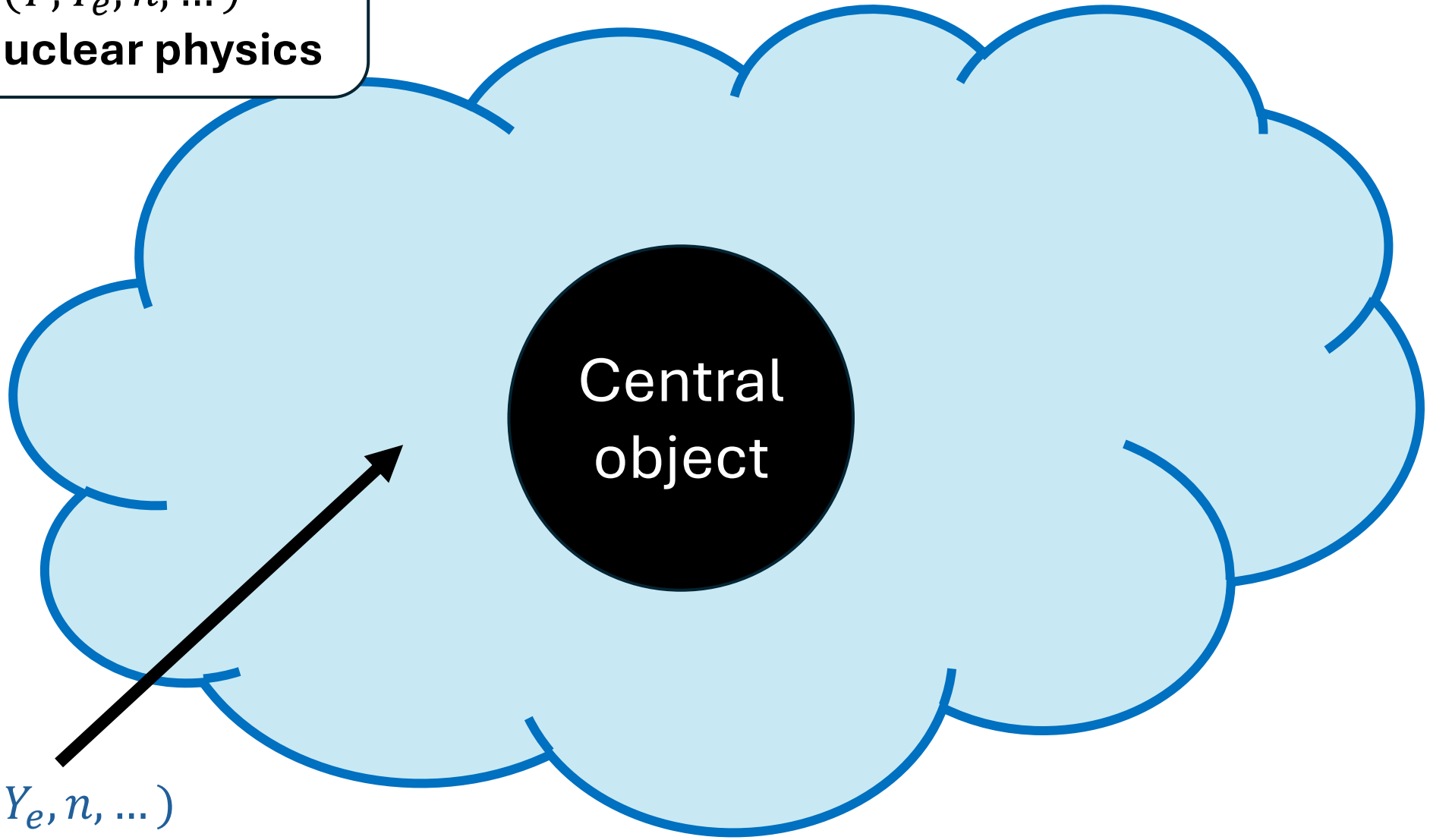

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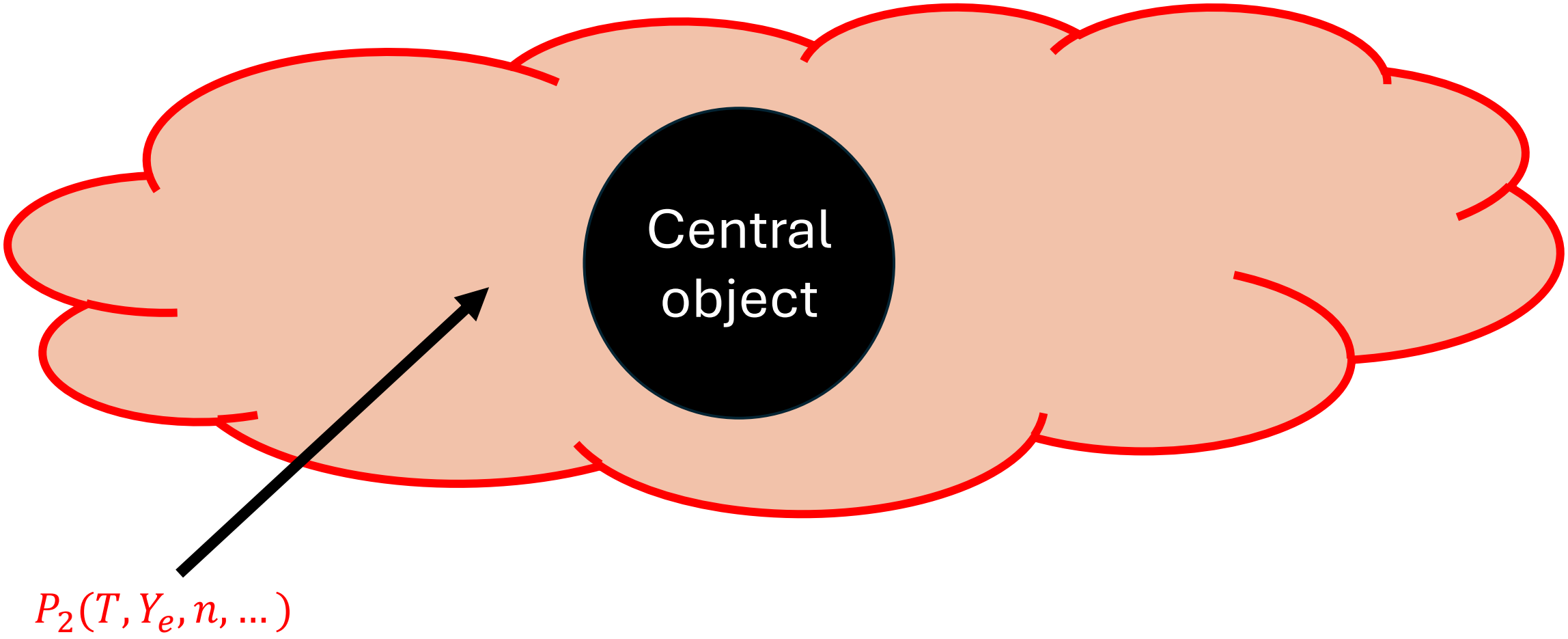


# Procedure

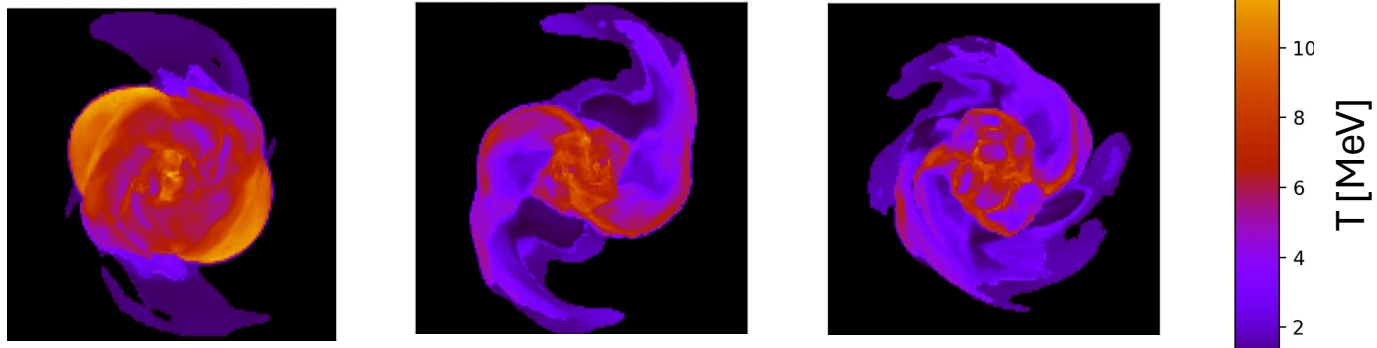
$$\frac{dN}{dE} = f(T, A, \dots)$$

Hydrodynamic simulation → Equation of state → Neutrino surface → Spectrum of emitted neutrinos → Comparison with observations

This is where I come into play…

Lagrangian describing nuclear interaction

SFHo | DD2 | NL3

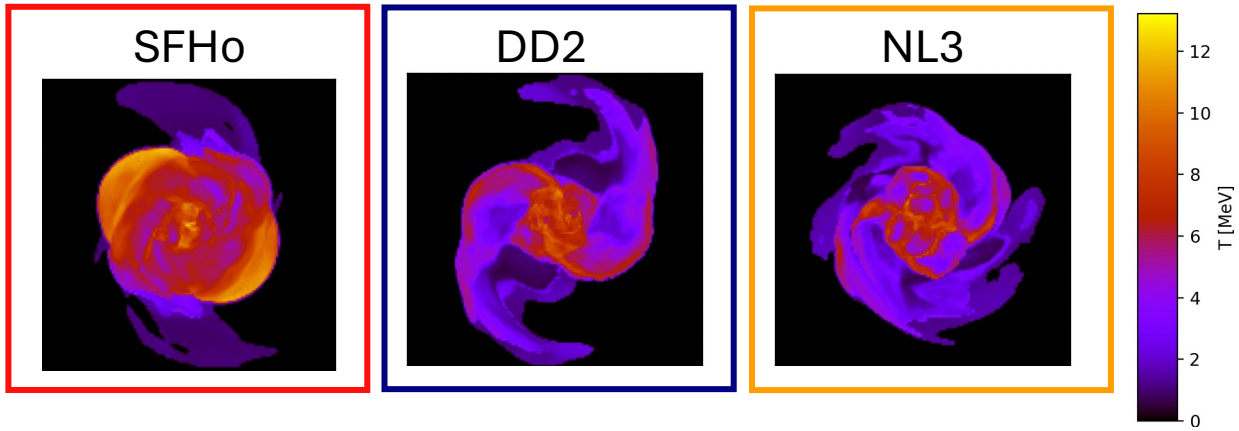


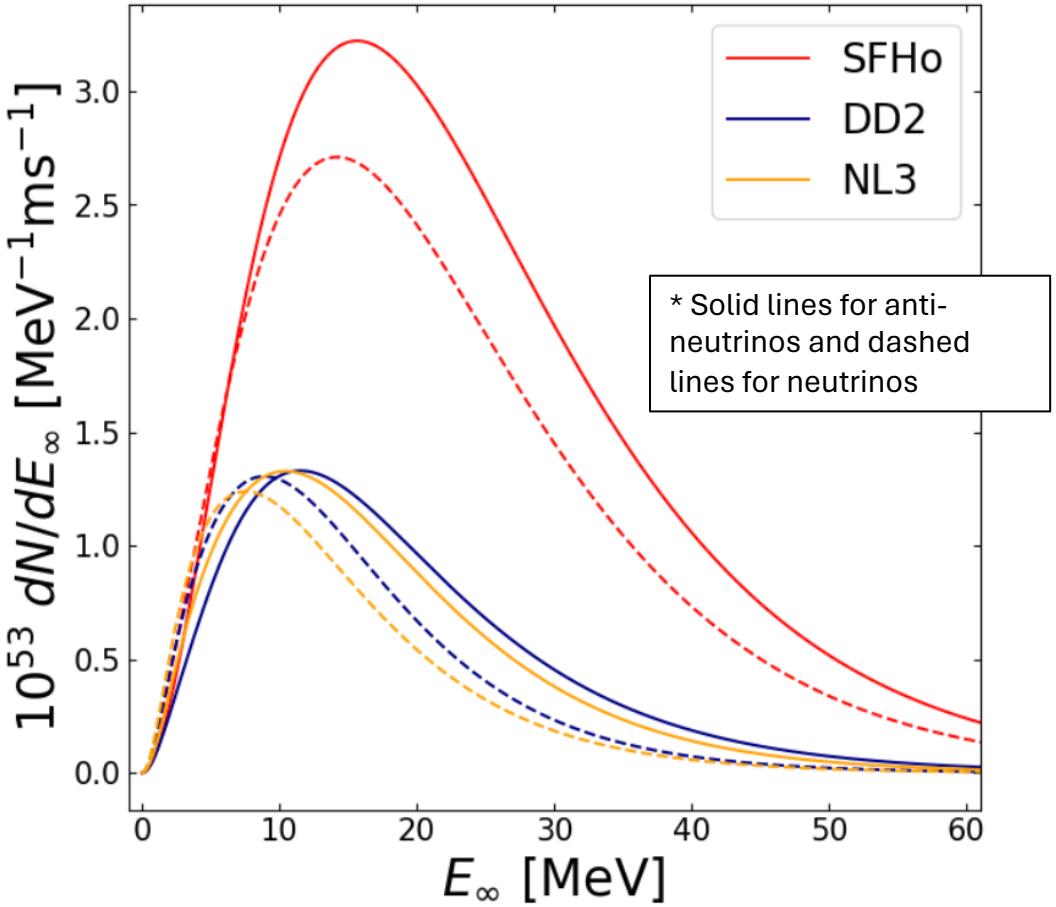

Palenzuela et al., 2015

Different T and shapes…

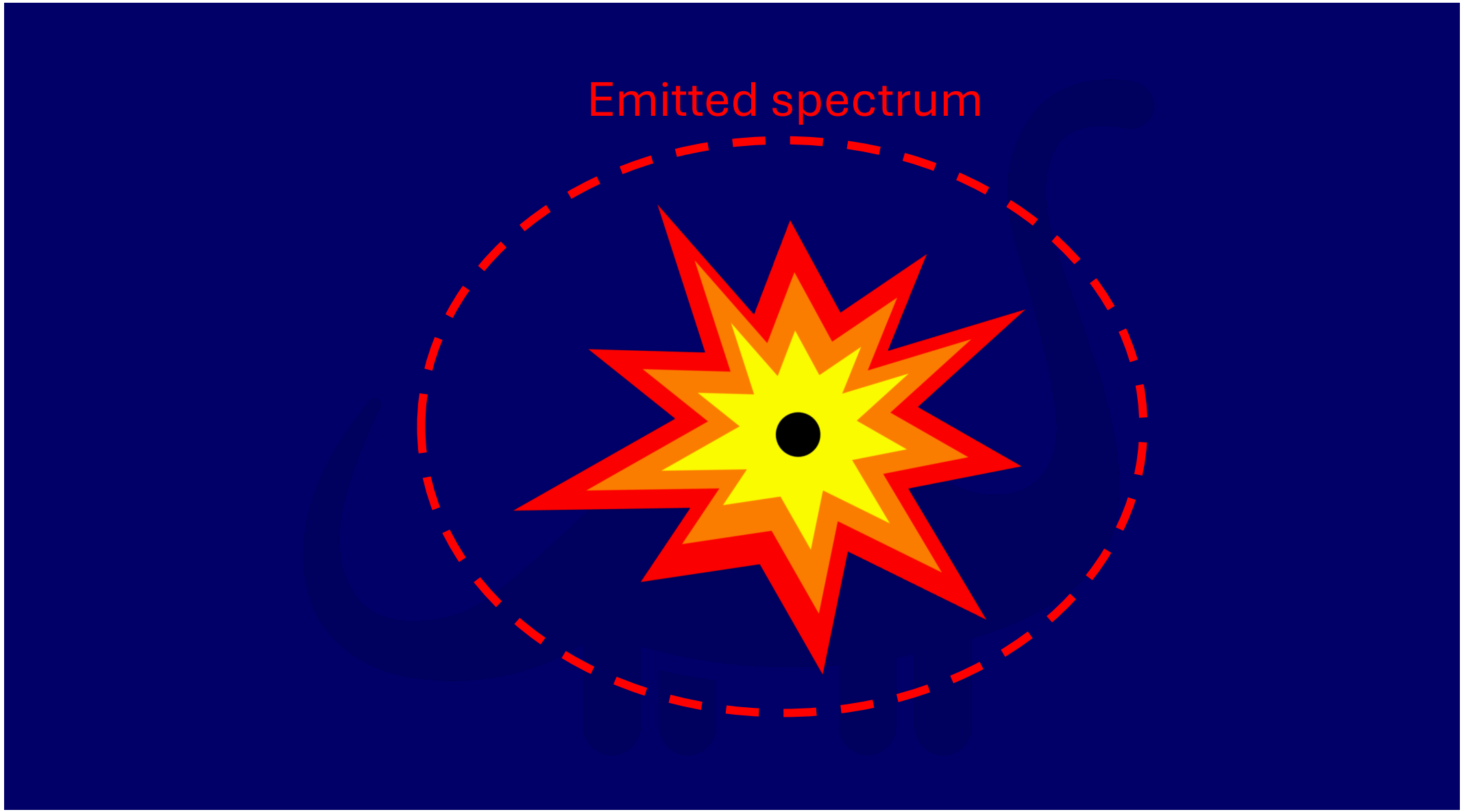
# Emitted spectrum

SFHo produces a different spectrum. **Great!!**

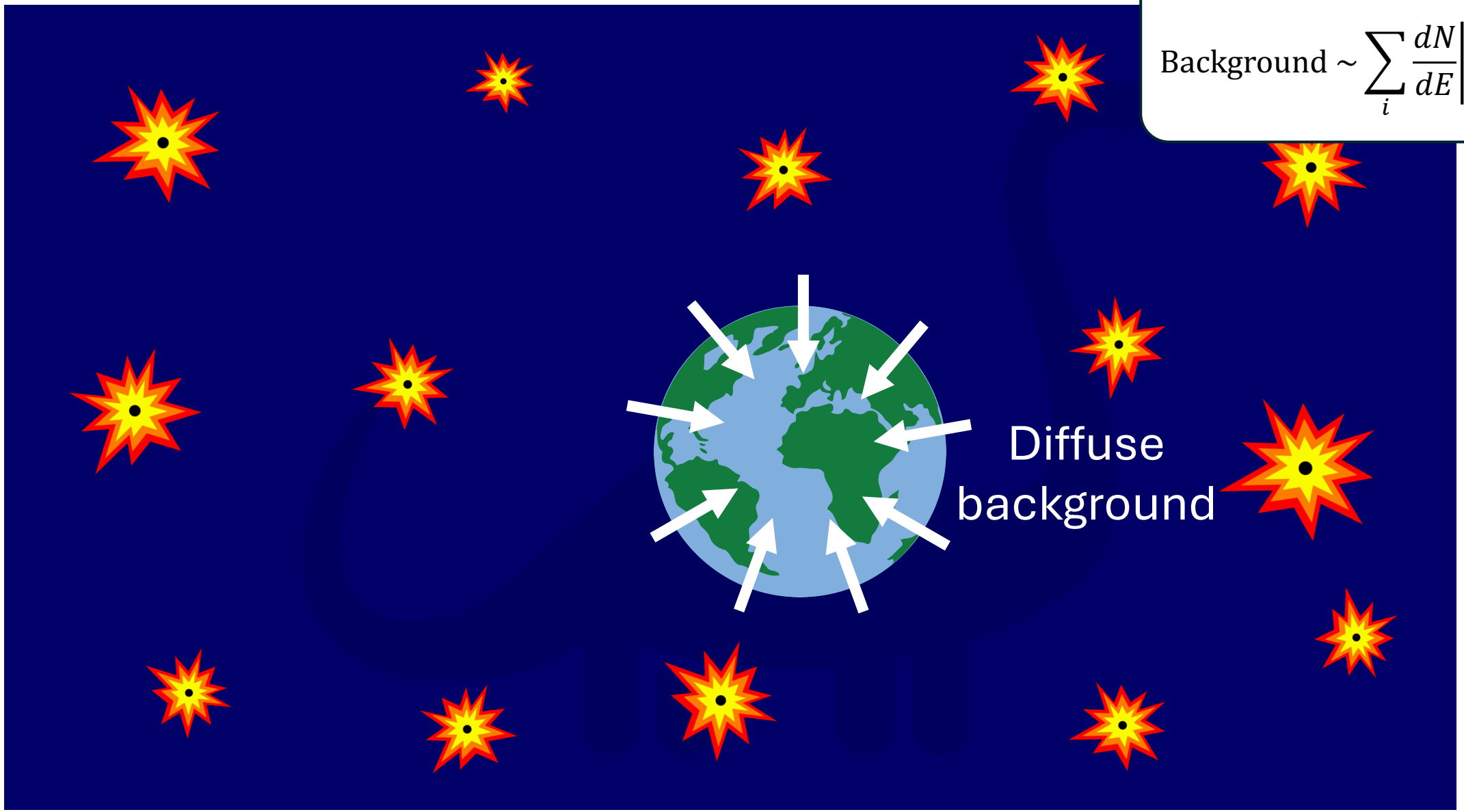


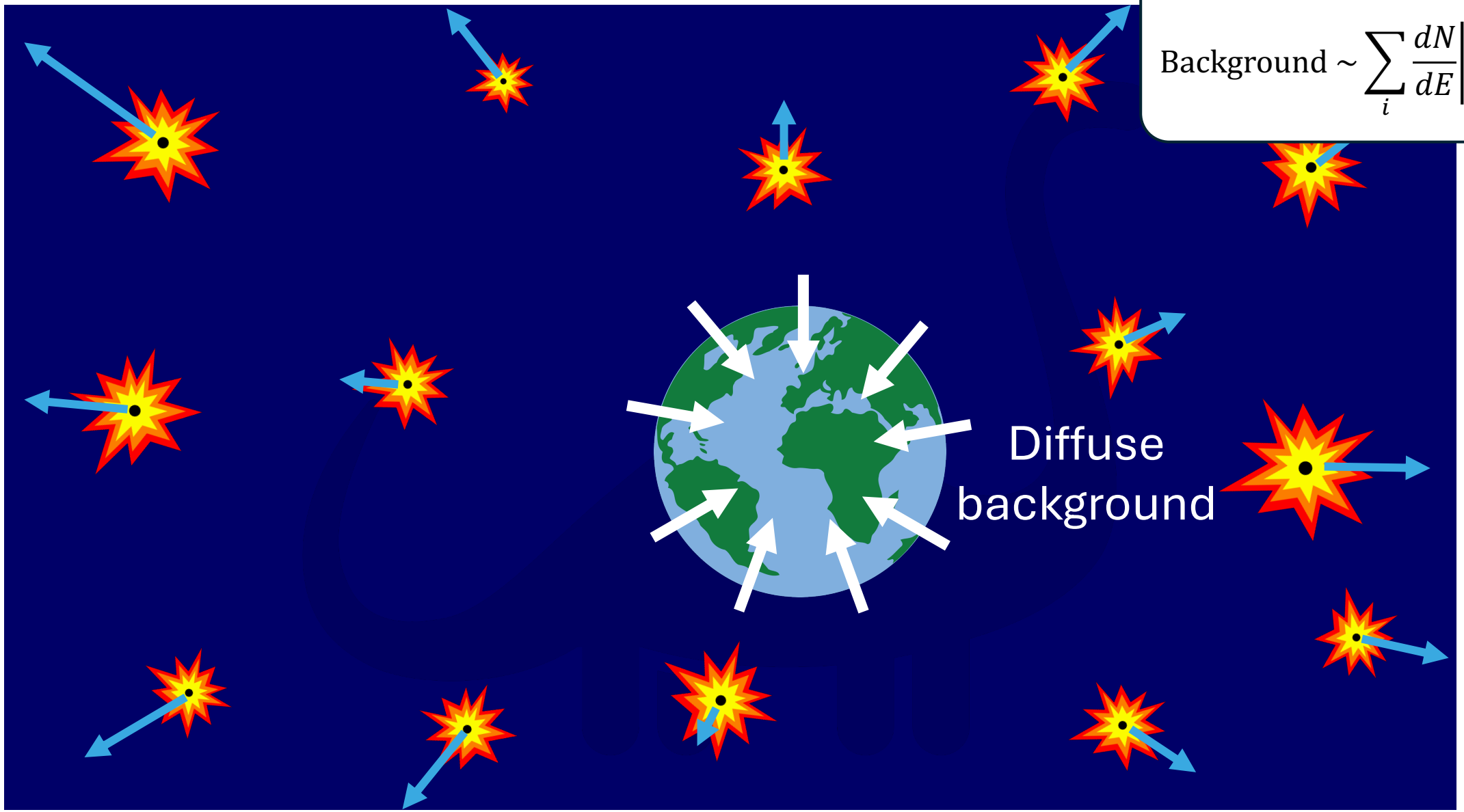

* Solid lines for anti-neutrinos and dashed lines for neutrinos


Emitted spectrum

$$\text{Background} \sim \sum_i \left.\frac{dN}{dE}\right|_i$$



$$\text{Background} \sim \sum_i \left.\frac{dN}{dE}\right|_i f(z_i)$$



How many neutrinos do we detect in observatories?

Depends on the observatory …

- Size of observatory,
- Efficiency of the detector,
- Material inside the observatory.

Diffuse background


HALO Collaboration

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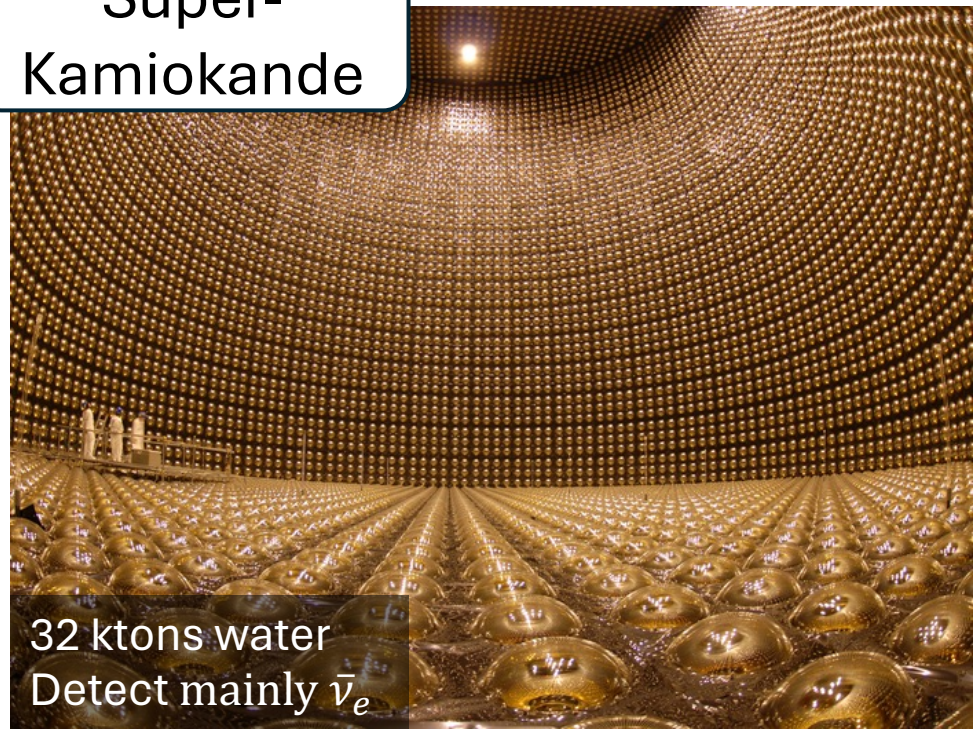
Super-Kamiokande




Kamioka Observatory, ICRR, The University of Tokyo

HALO


HALO Collaboration

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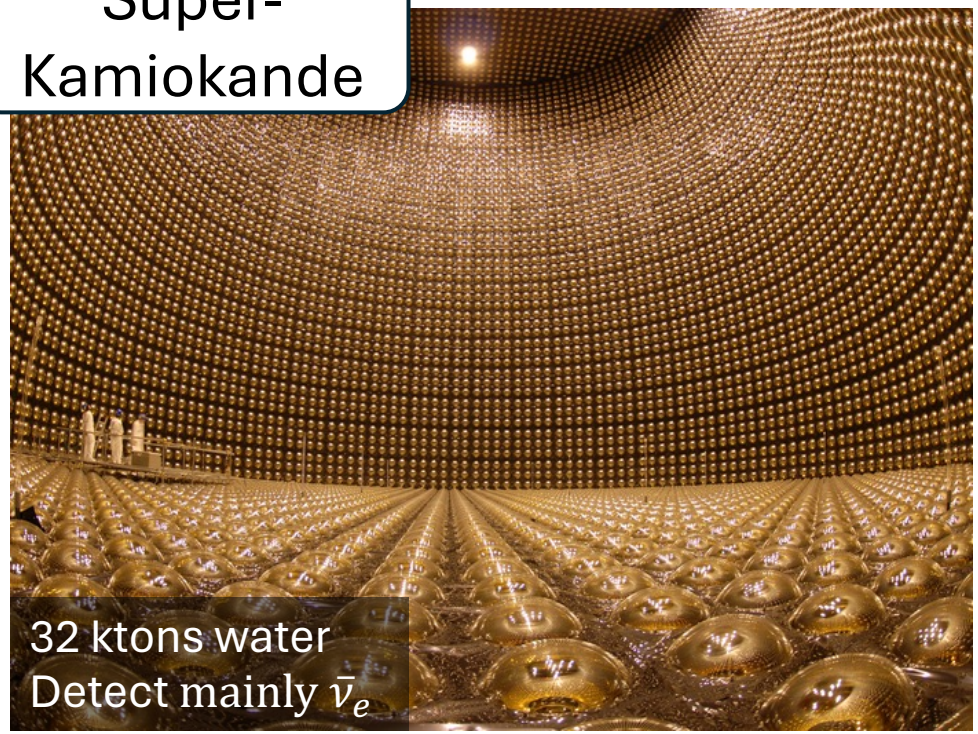
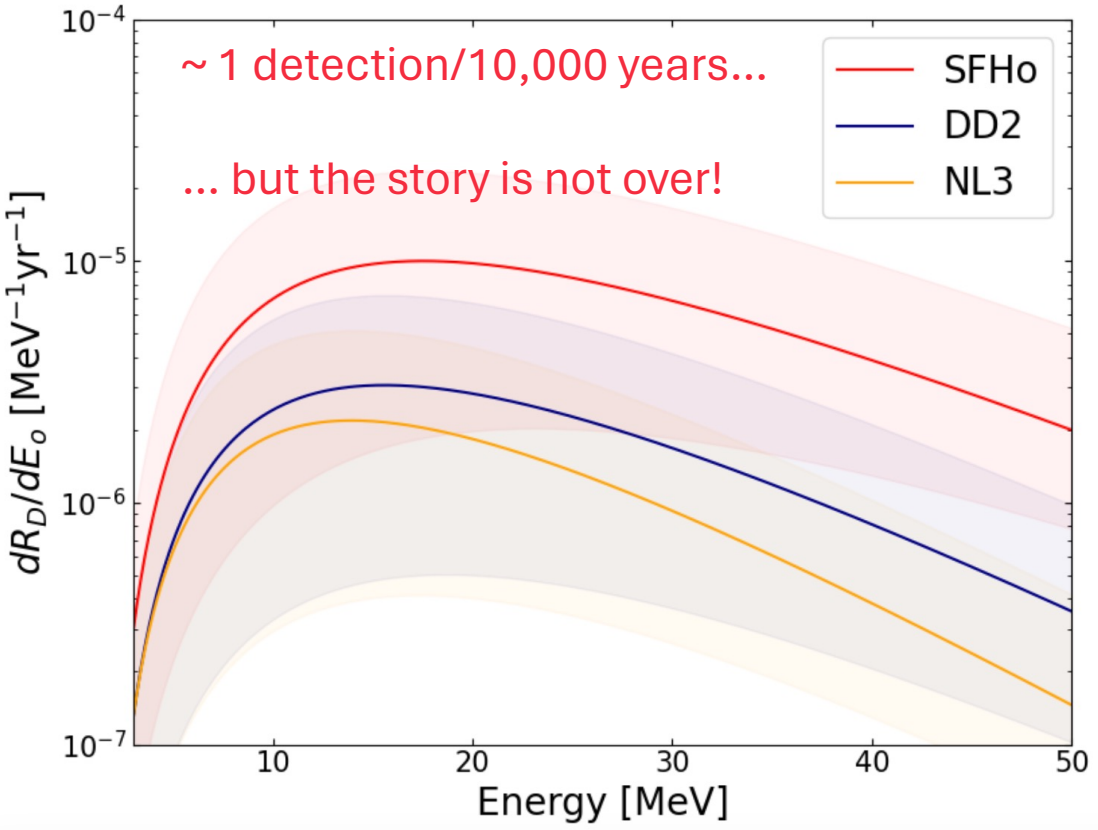
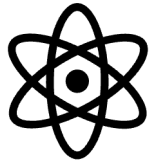
Super-Kamiokande




Kamioka Observatory, ICRR, The University of Tokyo



# Summary



Thermonuclear neutrinos produced in hot environments.

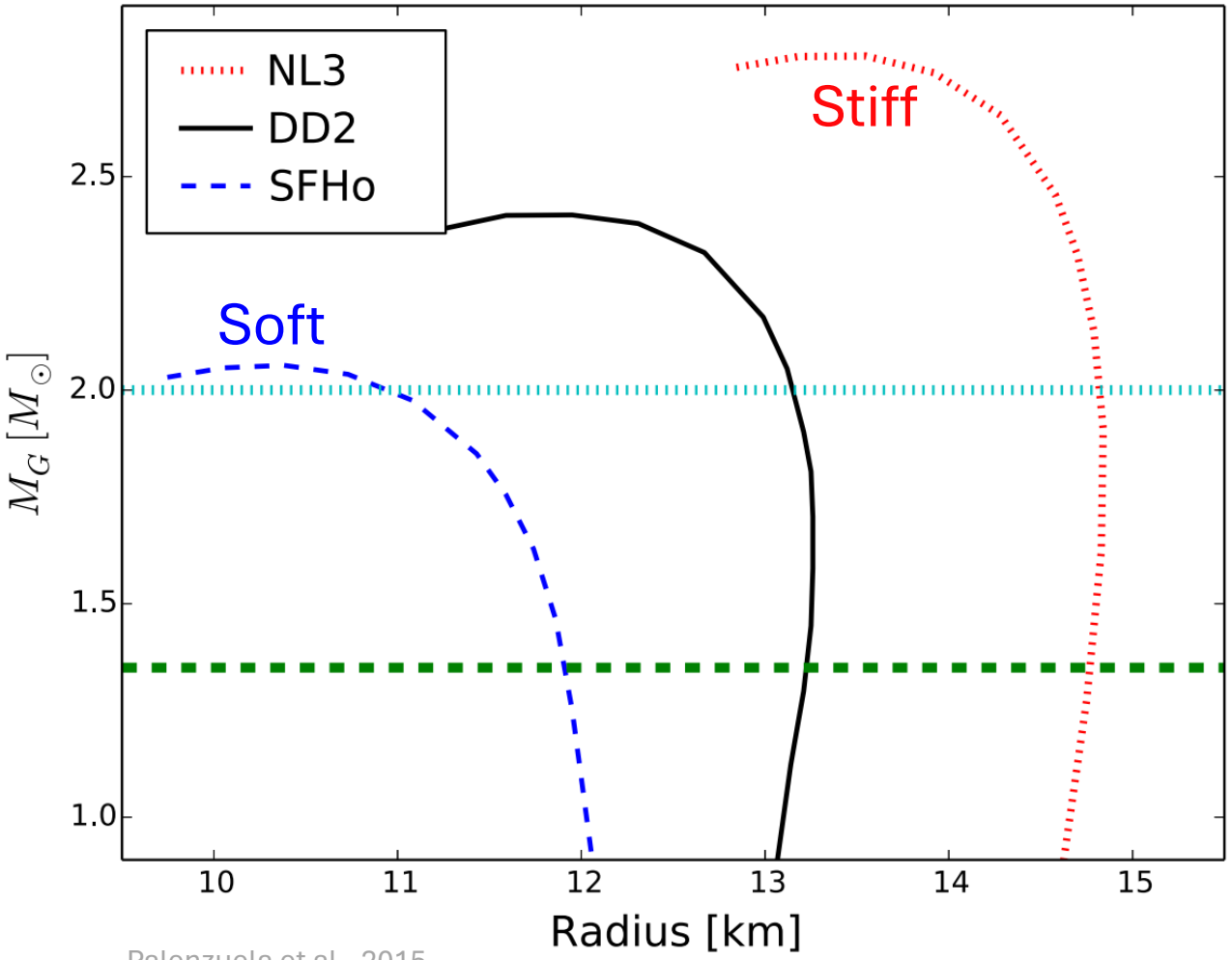
We use neutrinos to study the EOS of ultra-dense matter.

Different EOSs give different BNS neutrino background.

A further analysis is needed to observe the effect of the EOS.

# Thank you!

The research was conducted at the University of Guelph, which resides on the treaty lands and territory of the Mississaugas of the Credit. We recognize this gathering place where we work and learn is home to many past, present, and future First Nations, Inuit, and Métis peoples.




Palenzuela et al., 2015

Area (dA)
Height (z)
Temperature (T)

For 1 cell:

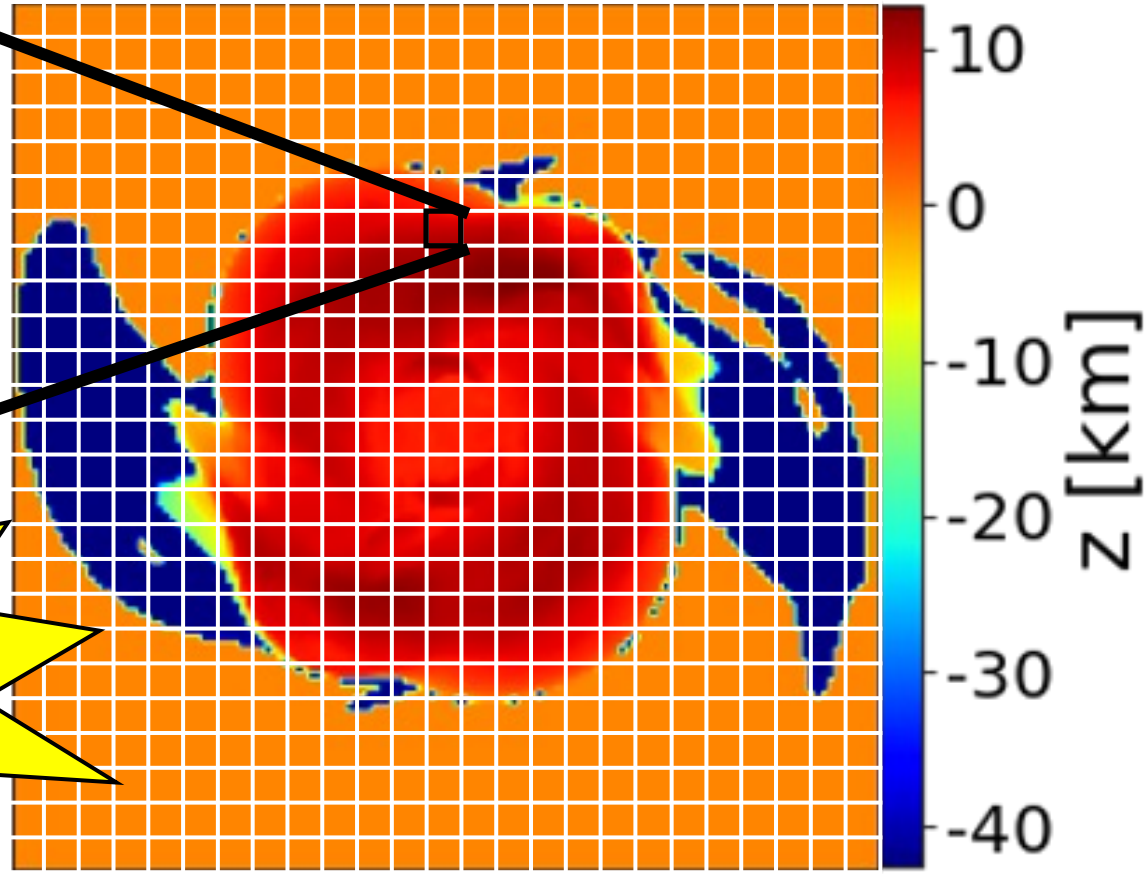
$$dN(E) \sim E^2 f(E,T) dA$$

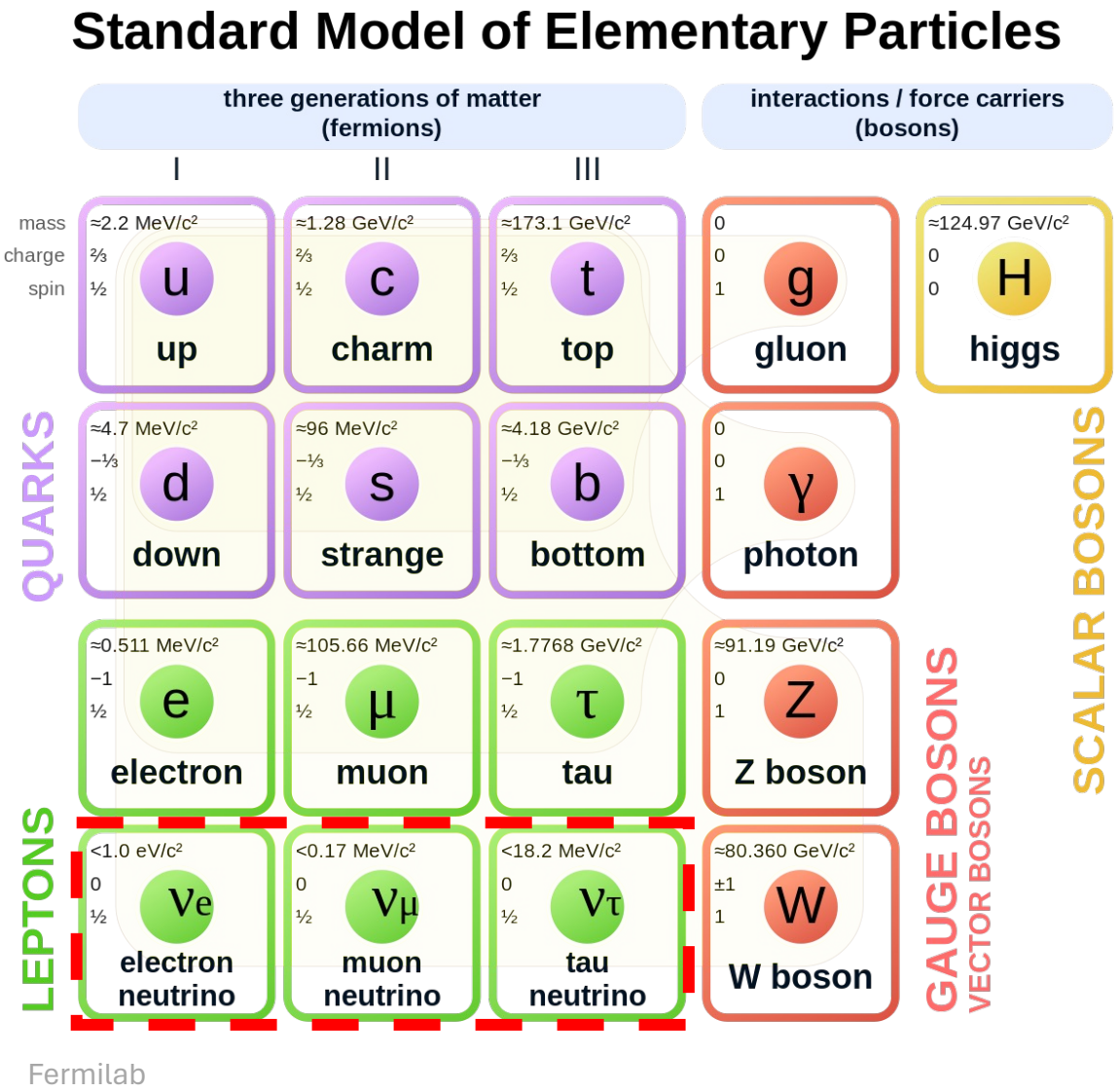
Neutrinos (s=1/2): Fermi-Dirac!

The spectrum looks like a sum of blackbody spectra…

For the whole surface:

$$N(E) \sim \sum_{ij} E^2 f(E)\, dA$$



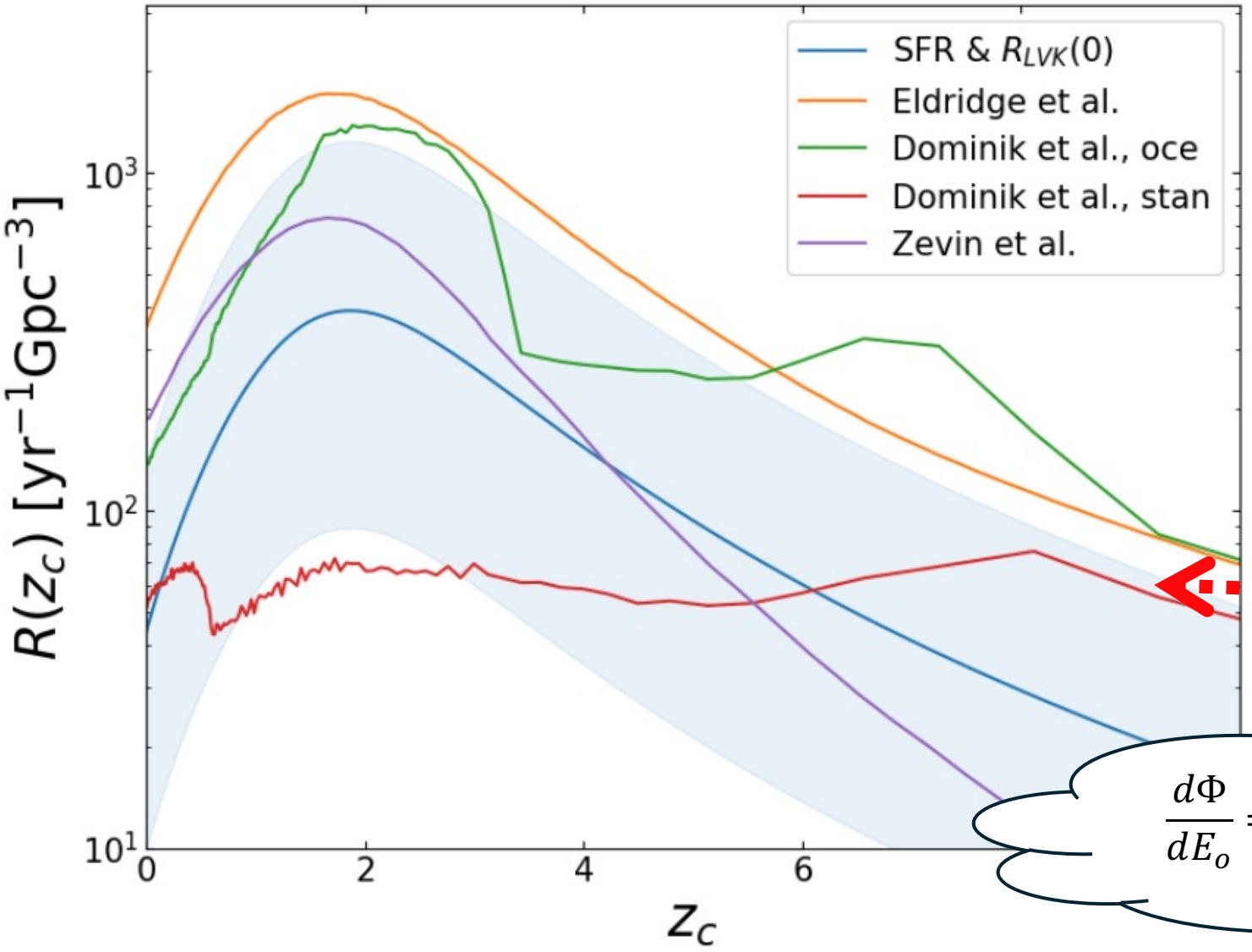



## Emission

$$n + e^+ \rightarrow p + \bar{\nu}_e$$
$$p + e^- \rightarrow n + \nu_e$$

## Detection

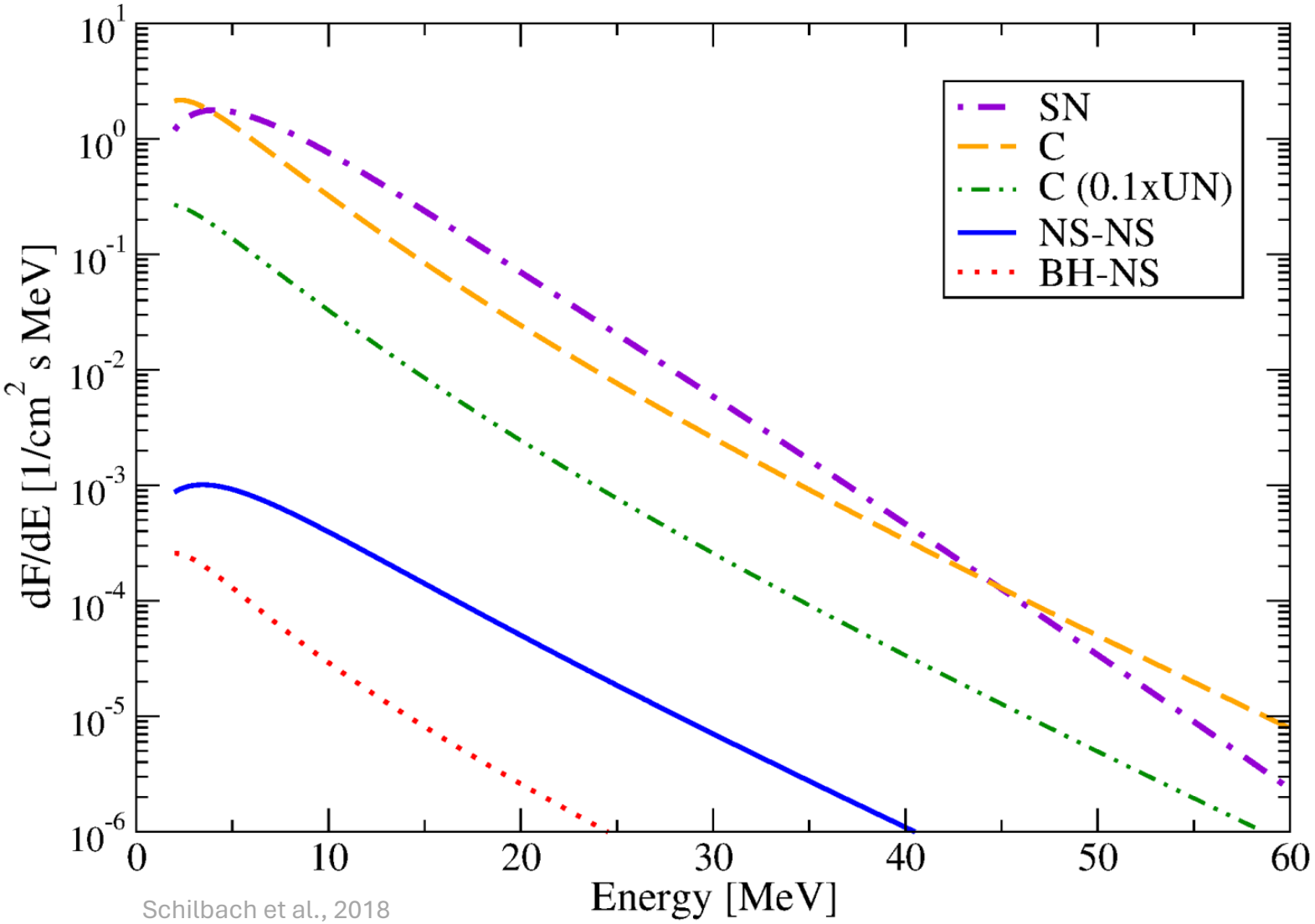
$$p + \bar{\nu}_e \rightarrow n + e^+$$
$$n + \nu_e \rightarrow p + e^-$$




Expansion of the universe

Neutrino spectrum

$$\frac{d\Phi}{dE_o} = -f_{osc} c \int dz_c R(z_c) f(z_c) \frac{dN}{dE_\infty}$$




Schilbach et al., 2018

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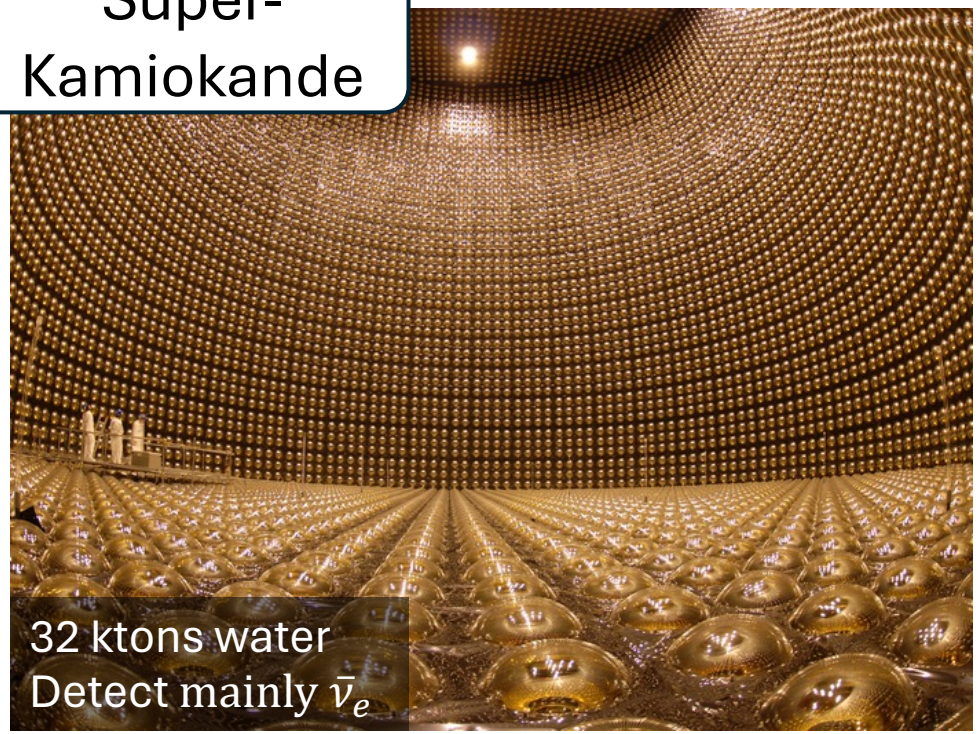


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